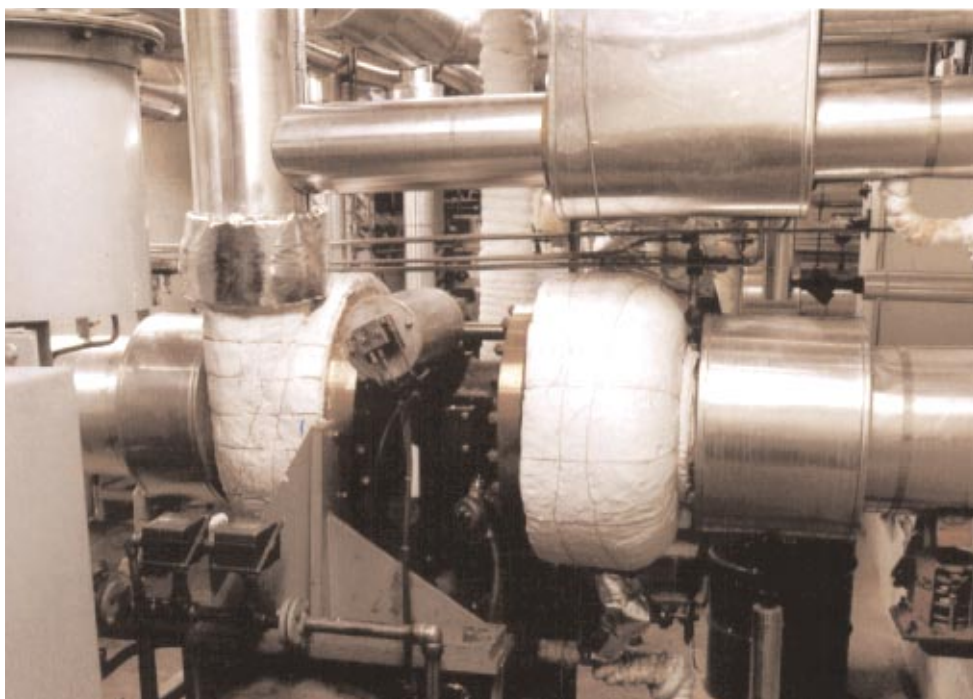


## **The economic thickness of insulation for hot pipes**



**ENERGY EFFICIENCY**

**BEST PRACTICE  
PROGRAMME**

The views and judgements expressed in this Fuel Efficiency Booklet are not necessarily those of the Department of the Environment, ETSU or BRECSU.

*Cover photograph courtesy of Courtaulds Fibres*

**CONTENTS**

---

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
<b>2</b>	<b>THE EFFECT OF INSULATION</b>	<b>1</b>
<b>3</b>	<b>THE ECONOMIC THICKNESS OF INSULATION</b>	<b>3</b>
	Basic requirements to estimate economic thickness	<b>4</b>
<b>4</b>	<b>TYPES OF INSULATION</b>	<b>5</b>
<b>5</b>	<b>THE ESTIMATION OF ECONOMIC THICKNESS</b>	<b>6</b>
	Use of specially prepared tables	<b>7</b>
	By customised tabulation	<b>7</b>
<b>6</b>	<b>ADAPTING TO AMBIENT CONDITIONS</b>	<b>12</b>
<b>7</b>	<b>ACKNOWLEDGEMENT</b>	<b>13</b>
<b>8</b>	<b>SOURCES OF FURTHER INFORMATION</b>	<b>13</b>
	<b>APPENDIX 1</b>	
	Some useful conversion factors	<b>15</b>
	<b>APPENDIX 2</b>	
	Tables reproduced from BS 5422: 1990	<b>16</b>
	<b>APPENDIX 3</b>	
	Heat loss graphs for various materials and surface temperatures	<b>25</b>
	Preformed rigid fibrous sections	<b>26</b>
	Preformed rigid calcium silicate or 85% magnesia sections	<b>36</b>
	Preformed rigid polyisocyanurate or polyurethane sections	<b>46</b>
	Preformed expanded nitrile rubber and polyethylene foam sections	<b>49</b>
	<b>APPENDIX 4</b>	
	Some basic heat transfer formulae	<b>51</b>

## INTRODUCTION

### 1 INTRODUCTION

This booklet is concerned with the economic thickness of insulation for hot pipes. Considerable amounts of data and practical advice is given, intended for use both by experienced personnel and as training material.

The cost of installing the insulation is offset by the large savings in fuel bills which can be achieved through insulating pipes. This booklet explains how to determine the thickness of insulation which will result in the optimum installation.

This booklet is concerned only with hot pipes, although the insulation of pipes operating below ambient temperature is also important. In particular, pipes forming part of domestic and non-domestic heating and hot water systems, and process pipework are covered. The information and techniques for determining the most economic thickness of insulation is consistent with BS 5422:1990.

This booklet is intended as a brief guide to the economic thickness of insulation for hot pipes, and therefore references are made throughout to the extensive documentation available from the insulation industry and the British Standards Institution (BSI).

Fuel Efficiency Booklet 19 - *Process Plant Insulation and Fuel Efficiency* - gives a broad picture of the use of insulation for process plant and should be read in conjunction with this booklet.

### 2 THE EFFECT OF INSULATION

Any surface which is hotter than its surroundings will lose heat. The rate at which heat is lost depends on many factors, but the temperature and area of the surface are often

dominant; the greater the temperature and area, the greater the loss. Adding an insulating layer to a hot surface reduces the external surface temperature. Although the surface area may be increased if insulation is added to a circular pipe, the relative effect of the temperature reduction is much greater and a reduction in heat loss is achieved.

Consider for example, a 15 mm bore pipe running through still air (at 20°C) carrying a hot fluid raising its external temperature to 75°C. The heat loss is about 60 W per metre of pipe run. The addition of a 25 mm thick layer of standard pipe insulation would increase the surface area by a factor of approximately 3.5, but the external surface temperature would fall from 75°C to around 23°C. The overall effect would be to reduce the heat loss from 60 W to 12 W per metre run of pipe.

Unwanted heat loss costs money. The loss of heat from a 100 m run of bare 50 mm bore pipe carrying process steam at 100°C, would cost around £3,000 per annum if the steam was supplied by a gas boiler with a gas cost of 1p/kWh (approximately 30p/therm). This cost would be reduced to £250 per annum if a 50 mm thick layer of appropriate insulation was applied. Thus, an annual saving of £2,750 would be achieved.

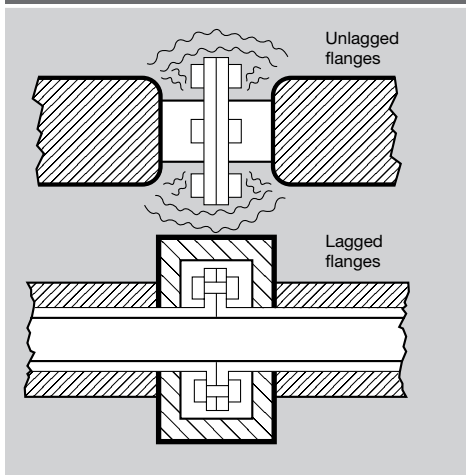
The 'avoidable' cost increases dramatically as the temperature of the process fluid increases. If the hot fluid was at 200°C, the 'bare pipe' cost would be around £10,000 per annum. This level of heat loss is equivalent to running a 1 kW electric fire night and day for more than 25 years. It could be reduced to £560 per annum if

## THE EFFECT OF INSULATION

a 75 mm thick layer of insulation were used (the insulation thickness must be increased as the pipe temperature increases, to ensure a suitable external surface temperature). In this case, there is an avoidable cost of £9,440 per annum.

The use of insulation on pipes carrying high temperature streams is a normal and accepted practice. It should not be assumed that any existing insulation provides the most effective arrangement for avoidable cost reduction. In many cases, thicker insulating layers would be well justified. All hot surfaces lose heat and, as shown in Fig 1, attention should be given to valves, flanges, etc., which are often left uninsulated for maintenance reasons. An uninsulated valve loses about the same amount of heat as 1 m of uninsulated pipe of the same diameter. Uninsulated flanges, which have a smaller surface area, lose about half this amount. Thus, a 50 mm valve carrying process steam at 200°C would cost about £100 per annum without insulation, but only about £6 per annum with appropriate insulation. The operation of valves need not be affected by insulation and it can be applied in easily removable sections to ease maintenance. An additional benefit is a more uniform metal temperature with a consequent reduction in

**Fig 1 Heat loss through unlagged flanges**



temperature induced stresses in the pipework system, which can be a cause of leakage at joints.

Although some form of insulation is normally found on high temperature pipework, low temperature small bore pipes, or pipes which are used only intermittently, are often completely neglected. However, as with valves and flanges, there is a considerable potential for avoidable cost savings. For example, the payback periods for 25 mm thick insulation on 15 mm pipe in a gas fired domestic heating

**Table 1 The Payback Period for Insulation on Domestic Central Heating Pipework**

<i>Number of Operating Hours</i>	<i>Payback Period (Years)</i>
1000	2
2000	1
3000	0.7
4000	0.5

*(Payback period assumes that the total cost for the installation of the insulation is £2 per metre)*

## THE ECONOMIC THICKNESS OF INSULATION

---

installation, for which the operating temperature would be typically 60 - 70°C, are as shown in Table 1. The payback period is the time taken to recoup the initial cost of an investment from the savings it produces.

### 3 THE ECONOMIC THICKNESS OF INSULATION

The examples presented in the previous Section give an indication of the cost savings which can be achieved by the use of insulation to prevent the unwanted dissipation of heat from pipework. For a given pipe and process conditions, the rate of dissipation is dependent on the thickness of the insulating layer and its thermal performance.

In most cases, the most important aspect of the insulation's thermal performance is thermal conductivity, a physical property which relates the rate at which heat is conducted through a material to the temperature difference across the conduction path. For the same thickness of insulation, heat losses are reduced as the thermal conductivity reduces. The effective thermal conductivity of an insulating layer may depend on the application procedure since this may influence, for example, the extent of voids or binder material. Operating temperature also affects the value of many insulating materials' thermal conductivity (see Section 4 'Types of insulation').

Other factors influencing thermal performance include surface properties which affect losses due to radiation. For example, radiation losses can be reduced by the addition of a shiny metallic skin to the insulating layer. The benefits of such an addition depend on actual conditions, but a 10% reduction in overall heat loss would not be untypical.

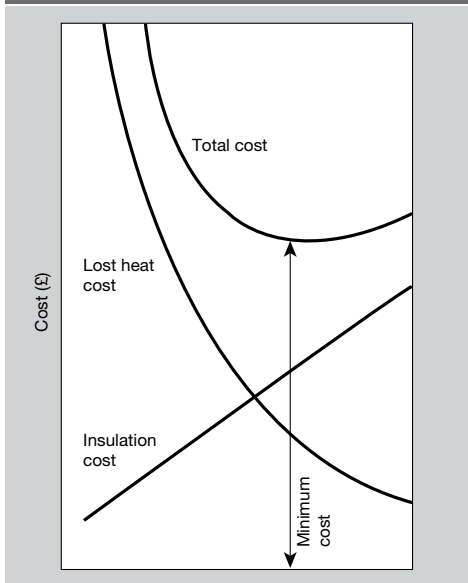
Manufacturers of insulation normally provide information on thermal performance which avoids the need for complex heat transfer calculations. The data, which are normally referred to as 'U' values, give the heat loss per unit length of pipe for a range of pipe diameters, process stream temperatures and insulation thicknesses. Whilst such data are useful for estimation purposes, it is important to note that the values are based on specified external conditions (often quiescent air at 20°C). Some caution must be exercised if the actual application conditions vary considerably from those used to establish the 'U' values.

It would be possible to reduce dissipative losses from pipework systems to effectively zero by an appropriate choice of material and thickness. The cost of operating a hot pipe is the cost of the heat loss, plus the cost of any insulation. In general terms, there is a cost penalty associated with increased thickness and improved thermal performance. Although higher expenditure results in greater cost savings, there is a point at which increased expenditure to improve the level of insulation cannot be justified by the additional savings which would arise.

The combined effect of increased expenditure due to increasing the thickness of the insulating layer, and increased cost saving, for a specific set of operating conditions, is illustrated in Fig 2. The minimum cost shown is the lowest combined cost of insulation and heat loss over a given period of time (the evaluation period). The minimum cost occurs at a particular thickness of insulation, referred to as the 'Economic Thickness of Insulation'. In practice, the curves are less smooth because

## THE ECONOMIC THICKNESS OF INSULATION

**Fig 2 Economic thickness of insulation**



many types of insulation are available only in certain thicknesses. Nonetheless, the principle still applies.

### Basic requirements to estimate economic thickness

Most of the information which is needed to estimate the economic thickness of insulation follows from Fig 2. In particular, data are required which allows the cost of heat loss from the pipework system over the evaluation period, and the cost of installing insulation to be determined. Both these items need to be established for a range of insulation thicknesses. In BS 5422:1990, the main reference for this booklet, evaluation period is defined as the total number of operating hours over which the investment is to be assessed,

i.e. it is the product of the annual operating hours and the life of the investment in years. Annual costs tend to be more meaningful than evaluation period costs. Consequently, in any analysis of economic thickness, the determination of annual costs is recommended, the evaluation period costs are easily established from the annual data. Ideally, the life of the investment would be based on the useful life of the insulation, but often company policies regarding investment criteria require a much shorter period to be used. The data required for the complete analysis of economic thickness can be summarised:

#### 1 To determine the annual cost of heat loss per metre run of pipe

Data requirements:

- The cost of fuel (In the normal units of purchase, e.g. pence/therm)
- The boiler efficiency (%)
- Annual operating period (hours)
- Heat loss per metre run of pipe (Watts/metre) which depends on:
  - Pipe size
  - Operating temperature
  - Type and thickness of insulation
  - Ambient conditions
 (Methods to estimate the heat loss from these data are given in Section 5)

#### 2 To determine the cost of insulation

Data requirements:

- Cost of material (£ per metre of pipe)
- Cost of ancillary materials (£ per metre of pipe)
- Labour costs (£ per metre of pipe)

#### 3 To determine the evaluation period

Data requirements:

- The investment life (years)
- Annual operating period (hours)

## TYPES OF INSULATION

The analysis to determine the economic thickness of insulation can be carried out from first principles using basic data. This procedure can incorporate both the exact detail of any particular application and the standard company method for assessing potential investment. For example, Discounted Cash Flow (DCF) techniques are employed by some organisations. At the other extreme, tables of economic thicknesses based on typical values of costs, etc., have been prepared. The use of such tables may not provide the optimum solution for a particular case, but they would normally provide a better answer than an arbitrary choice of thickness.

Before the methods of achieving a value for economic thickness are considered, it is useful to consider briefly the types of available insulation. Thermal performance and installation costs are affected by this choice.

### 4 TYPES OF INSULATION

Insulation material is classed as:

- *Inorganic* - based on crystalline or amorphous

siliceous/aluminous/calcium materials

- *Organic* - based on hydrocarbon polymers in the form of thermosetting/thermoplastic resins or rubbers.

The insulation material can be either flexible or rigid, both types of which are available in preformed pipe sections. Table 2 lists the common types along with relevant details.

Certain types of insulation can be applied by spraying and this might be appropriate for large pipes. Of the insulating materials listed in Table 2, mineral wool and polyurethane rigid foam can be applied in this way. Other insulating materials with a spray application option are vermiculite (maximum temperature 1,100°C) and alumino silicate (maximum temperature 1,260°C). A binder may be required.

The thermal conductivity of insulating materials varies considerably according to the type of material, its density and operating temperature. Table 3 gives a representative selection.

*Table 2 Insulating materials available in preformed pipe sections*

<i>Material</i>	<i>Approximate Maximum Temperature °C</i>	<i>Normal Bulk Density kg/m<sup>3</sup></i>
Mineral Wool (Glass)	230	15 - 100
Mineral Wool (Rock)	850	80 - 150
Magnesia	315	180 - 220
Calcium Silicate	800	190 - 260
Polyurethane Rigid Foam	110	30 - 160
Polyisocyanurate Rigid Foam	140	30 - 60
Phenolic Rigid Foam	120	35 - 200
Polythene	80	30 - 40
Synthetic Rubber	116	60 - 100

## THE ESTIMATION OF ECONOMIC THICKNESS

**Table 3 Thermal conductivities of insulating materials**

Material	Density kg/m <sup>3</sup>	Thermal Conductivity W/(m.K) Temperature °C		
		50	100	300
Calcium Silicate	210	0.055	0.058	0.083
Expanded Nitrile Rubber	65 - 90	0.039	–	–
Mineral Wool (Glass)	16	0.047	0.065	–
	48	0.035	0.044	–
Mineral Wool (Rock)	100	0.037	0.043	0.088
Magnesia	190	0.055	0.058	0.082
Polyisocyanurate Foam	50	0.023	0.026	–

Service temperature is an obvious criterion for the selection of an appropriate material, but other factors relating to the operating environment must also be taken into account. These include internal or external use, required surface finish, structural strength constraints and accessibility. Although materials exist to satisfy all common requirements, it is important to note that the economic thickness varies according to type because of differences in properties and costs.

Further details about insulation materials can be found in the TIMSA Handbook (available from The Thermal Insulation Manufacturers and Suppliers Association, PO Box 111, Aldershot, Hampshire, GU11 1YW) and BS 5970: 1992. Insulation for pipework is also discussed in Fuel Efficiency Booklet 19 - *Process plant insulation and fuel efficiency* - which gives general information on insulating a range of process plant and more details of surface finishes and general good practice.

### 5 THE ESTIMATION OF ECONOMIC THICKNESS

There are three different methods of estimating economic thickness. The first uses specially prepared tables based on assumptions about every item of data required to estimate economic thickness. The assumptions are reasonable for a wide range of applications and the tables are easy to use. However, there is a margin of error with this method, because specific details cannot be included. The second and more accurate method is the formulation of customised tables which do take account of specific details and which therefore provide a greater degree of confidence. These two methods will be described in detail in this Section

The third method of estimating economic thickness is an algebraic solution. This requires mathematical manipulation skills, but it has the least number of assumptions and is the most flexible of the three methods. It should only be attempted if a very precise value of thickness is needed, and often this is not a requirement

## THE ESTIMATION OF ECONOMIC THICKNESS

because many types of insulation are available only in certain specific sizes. For this reason, the algebraic method will not be described in this booklet. For a more detailed explanation of the technique, reference can be made to *Energy Efficiency for Technologists & Engineers*; Eastop & Croft, published by Longman Scientific & Technical; ISBN 0-582-03184-2.

### Use of specially prepared tables

Tables of the economic thickness of insulation for various types of application are included in BS 5422:1990. Values of the economic thicknesses have been tabulated for appropriate ranges of pipe sizes, pipe surface temperatures, (normally the process stream temperature), and insulation thermal conductivities. These tables have been reproduced in this booklet in Appendix 2 as follows:

- Non-Domestic heating and hot water services
  - Heating
    - solid fuel boiler Table 8
    - gas-fired boiler Table 9
    - oil-fired boiler Table 10
  - Hot water services Table 11
- Domestic heating and hot water services
  - Heating
    - heated areas Table 12
    - unheated areas Table 13
  - Hot water services
    - heated areas Table 14
    - unheated areas Table 15
- Process pipework Table 16

These tables provide the easiest method of determining the required value of economic thickness, but the conditions of the application under consideration should reasonably satisfy the assumptions used to derive the tabulated values. Use the tables in the absence of any

application data, but if data are available, they should be checked for consistency with the assumptions. Unless otherwise stated in Tables 8 to 16, ambient conditions are still air at 20°C.

Table 4 shows the fuel costs and evaluation period used to derive the tabulated values for the three application categories, non-domestic central heating and hot water services, domestic central heating and hot water services and process pipework. Fuel costs are expressed in pence per useful MJ. This is the cost of the fuel in pence per MJ divided by the efficiency of the boiler.

Table 17 gives the useful cost of heat for common fuels over a range of fuel prices, expressed in the normal purchase units, based on typical boiler efficiencies. For a particular purchase price, the useful cost of heat can be obtained directly from Table 17. Insulation costs are expressed in a particular way which is described below. In general terms, the economic thicknesses have been derived for estimates of fuel, insulation and installation costs which will apply in 1995.

### By customised tabulation

If the data relating to a particular application are significantly different from those forming the assumptions used to derive the tabulated values of economic thickness (Tables 8-16) a calculation specific to the application must be performed. The most straightforward method of calculation is to create a table which shows the total cost, i.e. the cost of the heat loss plus the insulation costs over the evaluation period, for a range of insulation thicknesses. The thickness which results in the minimum total cost can then be selected.



## THE ESTIMATION OF ECONOMIC THICKNESS

A table of the type shown in Fig 3 is required. Information described in Section 3, 'The economic thickness of insulation', must be available to complete the table. The meaning of the headings and the method of calculating the relevant values are as follows. Each heading has been assigned a step number, used to clarify the worked example given on Page 9.

### **Thickness of insulation (Step 1)**

The table is completed for a range of possible insulation thicknesses. If necessary, the first entry can be bare pipe, i.e. insulation thickness equals 0 mm, and successive entries made for each of the available thicknesses of the selected insulation. Alternatively, the tabulated values of economic thickness can be used as a guide to the approximate value and a range of thicknesses around this value used in the table.

### **Heat loss (Step 2)**

This is the rate of heat loss, in watts, per metre of pipe. It depends on the process stream temperature, the pipe diameter, the insulation thickness and ambient conditions. The heat loss can be determined conveniently from pre-prepared graphs (Graphs 1 - 25) which give the heat loss for a range of insulation types and thicknesses, pipe diameters and temperatures. For presentational convenience, these graphs are reproduced in Appendix 3. Table 5 summarises conveniently the content of each of the graphs. Use Table 5 to select the appropriate graph for the particular insulation type and pipe temperature relevant to the application under consideration. The use of these graphs is illustrated in Graph 3 which is based on a pipe temperature of 100°C insulated with performed rigid fibrous sections. The dotted lines show, for

example, that a 50 mm bore pipe with 50 mm of insulation would lose heat at 20 W/m; the same pipe without insulation would lose heat at 240 W/m. In a similar way, the value of heat loss can be determined for any combination of pipe bore and insulation thickness. If conditions are windy, refer to Section 6.

### **Cost factor (Step 3)**

The cost factor is the cost in pounds of one watt of heat loss per metre of pipe over the evaluation period. It depends on the evaluation period and the cost of useful heat. The stages in determining the cost factor are:

- i) Determine the number of MJ of heat which are lost per metre of pipe over the evaluation period if the rate of loss is one watt/metre. A watt is a joule per second. Therefore, if the evaluation period is expressed in hours, the number of joules which are lost with a one watt heat loss is:

$$\text{evaluation period} \times 3,600$$

A megajoule (MJ) is 1,000,000 joules (106 joules), therefore the number of MJ lost with a one watt heat loss is:

$$\text{evaluation period} \times 3,600 / 10^6$$

- ii) Determine the cost factor which is the product of the cost of useful heat in pence per MJ and the number of MJ lost, i.e.,  
 $\text{cost} \times \text{evaluation period} \times 3,600 / 10^6$   
 The result should be divided by 100 so that the cost factor is expressed in £/W

The two stages can be combined into a single formula:

$$\text{Cost factor} = \frac{\text{pence}}{\text{MJ}} \times \text{evaluation period} \times \frac{36}{10^6}$$

THE ESTIMATION OF ECONOMIC THICKNESS

**Cost of heat lost over evaluation period (Step 4)**

This is simply the total value of the heat lost per metre of pipe, for the particular thickness of insulation, over the evaluation period. The heat loss column gives the loss in watts per metre and the cost factor gives the cost in £/W for the evaluation period. Therefore, the cost of heat loss is given by:

Heat loss x Cost factor

**Installed cost of insulation (Step 5)**

This is the total cost of the insulation per metre of pipe inclusive of the cost of the insulating materials, the installation cost, surface finish, fixing materials etc. This cost must be determined for every thickness of insulation considered.

**Total cost (Step 6)**

This is the sum of the cost of heat loss over the evaluation period and the installed cost of insulation.

Table 5 Summary of heat loss graphs (Appendix 3)

Pipe Surface Temperature (°C)	Graph Number			
	Insulation Type			
	A	B	C	D
50	1	11	21	24
70				
75	2	12		25
100	3	13	22	
145			23	
150	4	14		
200	5	15		
300	6	16		
400	7	17		
500	8	18		
600	9	19		
700	10	20		

Insulation Types    A: Preformed rigid fibrous sections  
                              B: Preformed rigid calcium silicate or 85% magnesia sections (magnesia sections up to 300°C only)  
                              C: Preformed rigid polyisocyanurate or polyurethane sections (polyurethane sections up to 100°C only)  
                              D: Preformed expanded nitrile rubber and polyethylene foam sections

## THE ESTIMATION OF ECONOMIC THICKNESS

### Example:

The following example shows the use of the customised tabulation method for estimating economic thickness.

A non-domestic heating system uses steam at slightly over 100°C supplied through 50 mm bore pipes. The steam is supplied by a gas boiler which is 70% efficient and the cost of gas is 28 pence per therm. Preformed fibrous insulation material (thermal conductivity - 0.055 W/(m.K) ) is to be used. The total cost of installed insulation for the various thicknesses available from the manufacturer is as follows:

19 mm thickness	£1.40/m
25 mm	£2.00/m
32 mm	£2.30/m
38 mm	£2.90/m
50 mm	£8.40/m

The evaluation period is 22,000 hours (5 year investment life with 4,400 hours of operation per annum) and the pipework can be assumed to run through still air at 20°C.

### Step 1 Thickness of insulation

For this application, Table 9 indicates that the economic thickness is 37 mm (tabulated results for a pipe with an outside diameter of 60.3 mm are the closest to the proposed application). Consequently estimates around this thickness are likely to be required and the first estimate of economic thickness should be 25 mm. The values for each of the columns of the estimating table can now be evaluated.

### Step 2 Heat Loss

Graph 3 is the appropriate heat loss graph for this application. This shows that a 50 mm bore pipe with 25 mm of preformed fibrous insulation would lose heat at the rate of 30 W/m.

### Step 3 Cost Factor

Table 17 indicates that the useful cost of heat for a gas boiler with 70% efficiency and a fuel cost of 22.16 p/therm is 0.30 p/MJ and for a fuel cost of 29.54 p/therm the useful cost is 0.40 p/MJ. In this particular application the gas cost is 28 p/therm and the useful cost of heat must be estimated. Simple proportionality can be used; for this application, the useful cost is given by:

$$\text{Useful Cost} = \left( \frac{0.30}{22.16} \right) = 0.38 \text{ p/MJ}$$

The evaluation period is 22,000 hours and, therefore, the cost factor is given by:

$$\text{Cost Factor} = 0.38 \times 22,000 \times \left( \frac{36}{10^6} \right) = 0.30 \text{ £/W}$$

Note that the cost factor is the same for all insulation thicknesses.

### Step 4 Cost of heat lost over evaluation period

The product of the cost factor and the heat lost. Therefore:

$$\text{Cost of heat} = 30 \times 0.30 = £9.00/\text{m}$$

### Step 5 Installed cost of insulation

Given as £2.00/m

### Step 6 Total cost

The sum of the cost of heat and the installed cost of insulation (Step 4 + Step 5), i.e.:

$$\text{Total Cost} = 9.00 + 2.00 = £11.00/\text{m}$$

Similar calculations are used for all the other thickness values and the results have been tabulated in Table 6. This shows that the minimum cost occurs with an insulation thickness of 38 mm and this should be the thickness selected. Note that in this example the tabulation method gives approximately the same value of economic thickness as given in the pre-prepared tables. THIS WILL NOT BE TRUE FOR EVERY APPLICATION. It must also be remembered that the values for Total Cost are heavily dependent on the investment criteria of the organisation.

## ADAPTING TO AMBIENT CONDITIONS

**Table 6 Example of economic thickness determination by tabulation**

Thickness of insulation mm	Heat Loss W/m	Cost Factor £/W	Cost of Heat Loss £/m	Installed Cost of Insulation £/m	Total Cost £/m
25	30	0.30	9.00	2.00	11.00
32	26	0.30	7.80	2.30	10.10
38	23	0.30	6.90	2.90	9.80
50	20	0.30	6.00	8.40	14.40

### 6 ADAPTING TO AMBIENT CONDITIONS

All the procedures indicated above have been based on ambient conditions of still air at 20°C. Air motion, which in most practical applications will be due to wind, and a different ambient temperature, can have a significant effect on the rate of heat loss and, consequently, the economic thickness of insulation.

Wind speed can have a large effect on the heat loss from bare pipes as shown in Table 7. This gives multiplying factors for bare pipe heat losses compared with those in still air conditions shown in Graphs 1 - 25.

The factors for high, medium and low emissivity surfaces refer to the nature of the outer surface of the pipe. As a guide, a painted

surface would normally have a high emissivity, oxidised steel a medium emissivity and polished aluminium a low emissivity.

If there is no data on typical wind speeds, the following values are recommended:

Sheltered situations	1 m/s
Normal situations	3 m/s
Exposed situations	10 m/s

Fortunately, for insulated pipes the effect of exposure to wind speed alone will not normally increase the heat loss from a well insulated pipe by more than 10% even in exposed conditions. This is because the thermal resistance of the insulation is the dominant factor in determining the rate of heat loss.

**Table 7 Wind speed correction factors for heat losses from bare pipes only**

Wind Speed (m/s)	Multiplying Factors		
	High Emissivity Surface	Medium Emissivity Surface	Low Emissivity Surface
Still Air	1.00	1.00	1.00
1	1.35	1.44	1.58
2	1.65	1.81	2.11
3	2.00	2.25	2.72
5	2.60	3.00	3.86
10	4.00	4.75	6.32

## SOURCES OF FURTHER INFORMATION

Variations in ambient temperature also affect the rate of heat loss, which in general is proportional to the difference between the pipe (fluid) temperature and the ambient temperature. For example, if the average ambient temperature is 10°C as opposed to 20°C, and the pipe temperature is 150°C, the rate of heat loss will be 7.7% ( $10 \div 130$ ) greater.

For outdoor insulated piping in the UK, a rough guide would be to increase the still air, 20°C ambient, heat loss rate by 15% - 20% to take account of the lower air temperature and exposure to winds.

It is necessary to emphasise the importance of cladding or sealing outdoor insulation to make it waterproof as far as possible. The heat losses from wet insulation will far exceed the heat losses through dry material.

### 7 ACKNOWLEDGEMENT

The Department of the Environment is grateful to the British Standards Institution for permission to reproduce material from BS5970: 1992 and BS 5442: 1990.

### 8 SOURCES OF FURTHER INFORMATION

#### ■ *British Standards:*

The following British Standards contain further information on thermal insulation, its specification and sources of supply:

BS 5422:1990 - *Method for specifying thermal insulating materials on pipes, ductwork and equipment (in the temperature range -40°C to +700°C)*

BS 5970:1992 - *Code of practice for thermal insulation of pipework and equipment (in the temperature range -100°C to +870°C)*

Copies of these British Standards are available from:

British Standards Institution  
Sales Department  
Linford Wood  
Milton Keynes  
MK14 6LE

#### ■ *Insulation Suppliers:*

TIMSA Handbook: *The Specifiers Insulation Guide 1992*

Copies of this publication are available from:  
Thermal Insulation Manufacturers and Suppliers Association

PO Box 111  
Aldershot  
Hampshire  
GU11 1YW  
Tel: 01252 336318

#### ■ *Energy Efficiency Best Practice programme publications:*

Copies of literature applicable to insulation and to energy efficiency in industry in general are available from:

Energy Efficiency Enquiries Bureau  
ETSU  
Harwell  
Didcot  
Oxon  
OX11 0RA  
Tel: 01235 436747  
Fax: 01235 433066

■ *The latest news in energy efficiency technology*  
*Energy Management* is a free journal issued on behalf of the DOE which contains information

## SOURCES OF FURTHER INFORMATION

---

on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation.

Copies of Energy Management can be obtained through:

Emap Maclaren Limited  
Maclaren House  
19 Scarbrook Road  
Croydon  
Surrey  
CR9 1QH

## APPENDIX 1

### SOME USEFUL CONVERSION FACTORS

*Conversion factors for units used in this booklet*

	SI				Imperial
Temperature	°C	x	1.8	+ 32	= °F
Length	mm	x	0.0394	=	in
	m	x	3.2808	=	ft
Volume	litres	x	0.2200	=	gal
Weight	tonne	x	0.9842	=	ton
Energy	GJ	x	9.4782	=	therm
Heat flow rate	W/linear m	x	1.0400	=	Btu/ft h
Thermal conductivity	W/m K	x	6.9335	=	Btu in/ft <sup>2</sup> h °F
Thermal conductance	W/m <sup>2</sup> K	x	0.176	=	Btu/ft <sup>2</sup> h °F

For heavy fuel oil the number of litres in tonne = 1,020

Medium fuel oil the number of litres in a tonne = 1,040

Gas oil the number of litres in a tonne = 1,180

## APPENDIX 2 TABLES REPRODUCED FROM BS 5422: 1990

### TABLES REPRODUCED FROM BS 5422: 1990

**Table 8 Economic thickness of insulation for non-domestic heating installations served by solid fuel-fired boiler plant**

Outside diameter of steel pipe on which insulation thickness has been based (in mm) <sup>1</sup>	Hot face temperature (in °C) (with ambient still air at +20°C)											
	+ 75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	14	17	20	23	17	21	24	26	22	25	28	32
21.3	15	18	22	24	17	22	25	27	23	26	30	34
26.9	17	20	23	25	20	24	26	28	24	28	32	35
33.7	17	21	24	26	20	25	27	31	25	29	34	37
42.4	18	22	25	27	21	25	28	32	25	31	35	39
48.3	18	23	25	28	22	26	29	33	26	32	36	41
60.3	19	24	26	29	23	27	31	35	27	33	38	43
76.1	20	24	27	31	23	28	33	36	28	35	40	45
88.9	20	24	28	32	24	28	33	37	29	36	42	46
114.3	21	25	29	33	25	30	35	39	31	37	44	48
139.7	22	26	30	34	25	31	36	41	31	38	45	50
168.3	22	26	31	35	25	32	37	42	32	40	46	52
219.1	22	27	32	36	26	33	38	43	33	42	48	54
273.0	23	27	33	36	26	34	39	44	34	43	49	55
Above 323.9 and including flat surfaces	23	28	34	38	27	35	42	47	35	45	53	60

<sup>1</sup> Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.

**TABLES REPRODUCED FROM BS 5422: 1990**

**Table 9 Economic thickness of insulation for non-domestic heating installations served by gas boiler plant**

Outside diameter of steel pipe on which insulation thickness has been based (in mm) <sup>1</sup>	Hot face temperature (in °C) (with ambient still air at +20°C)											
	+ 75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	17	22	24	26	20	24	27	31	24	29	34	37
21.3	18	23	25	27	22	25	29	33	26	32	36	39
26.9	20	24	26	29	23	27	31	34	27	33	38	42
33.7	21	25	27	31	24	28	33	36	28	35	40	44
42.4	22	25	29	32	25	30	34	38	30	37	42	47
48.3	22	26	30	33	25	31	35	39	31	38	44	48
60.3	23	27	32	35	26	32	37	41	33	39	46	50
76.1	24	28	33	36	27	34	39	43	34	42	48	52
88.9	24	29	34	37	28	35	40	45	35	43	49	53
114.3	25	31	35	39	29	36	42	47	36	45	51	56
139.7	25	32	36	41	30	37	43	48	37	47	53	59
168.3	25	32	37	42	31	38	45	50	38	48	56	61
219.1	26	33	38	44	32	40	46	52	40	51	58	65
273.0	27	34	40	45	33	41	47	53	41	52	59	68
Above 323.9 and including flat surfaces	27	36	42	47	34	43	51	58	42	54	63	72

<sup>1</sup> Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.

TABLES REPRODUCED FROM BS 5422: 1990

**Table 10** *Economic thickness of insulation for non-domestic heating installations served by oil-fired plant*

Outside diameter of steel pipe on which insulation thickness has been based (in mm) <sup>1</sup>	Hot face temperature (in °C) (with ambient still air at +20°C)											
	+ 75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	18	23	25	28	22	26	29	33	26	32	36	40
21.3	19	24	27	29	23	27	32	35	27	34	38	43
26.9	21	25	28	32	24	29	33	36	29	35	41	45
33.7	22	26	29	33	26	31	35	38	31	37	43	47
42.4	23	27	32	35	26	32	37	41	32	39	45	50
48.3	24	28	33	36	27	33	38	42	33	41	46	51
60.3	25	29	34	37	28	35	39	44	35	43	49	52
76.1	25	31	35	39	29	36	42	46	36	45	50	55
88.9	25	32	36	41	30	37	43	48	37	46	51	57
114.3	26	33	38	43	31	38	44	49	39	48	54	60
139.7	27	34	39	44	33	41	47	51	41	50	57	63
168.3	27	35	41	45	33	42	48	54	42	52	59	66
219.1	28	36	42	47	34	43	51	56	43	54	62	69
273.0	29	37	43	48	35	44	52	57	45	55	64	71
Above 323.9 and including flat surfaces	31	38	45	52	37	47	55	62	47	60	69	77

<sup>1</sup> Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.

TABLES REPRODUCED FROM BS 5422: 1990

Table 11 Economic thickness of insulation for non-domestic hot water services

Outside diameter of steel pipe on which insulation thickness has been based (in mm) <sup>1</sup>	Water temperature +60°C)											
	Solid Fuel				Gas				Oil			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	17	21	24	27	20	24	28	32	22	27	31	34
21.3	18	22	25	28	22	26	30	34	23	28	32	36
26.9	20	23	27	29	23	28	32	35	24	29	34	38
33.7	20	24	28	31	24	29	33	37	26	31	36	40
42.4	21	26	30	33	25	31	34	39	28	33	38	42
48.3	22	27	31	34	26	32	36	40	29	34	39	43
60.3	23	28	32	36	27	33	38	42	30	36	41	45
76.1	23	29	34	37	28	35	40	44	31	37	42	47
88.9	24	30	35	38	29	36	41	45	32	38	44	48
114.3	25	31	36	40	30	37	43	47	33	40	46	51
139.7	25	32	37	41	31	38	44	50	34	41	47	54
168.3	26	33	38	42	32	39	45	52	34	42	51	56
219.1	26	34	39	44	33	41	47	55	35	44	53	59
273.0	27	35	40	45	34	42	51	57	36	45	55	61
Above 323.9 and including flat surfaces	29	36	42	50	35	44	54	61	40	51	59	65

<sup>1</sup> Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.

## TABLES REPRODUCED FROM BS 5422: 1990

**Table 12** *Economic thickness of insulation for domestic central heating installations in heated areas*

Outside diameter of copper pipe (in mm)	Water temperature of +75°C with ambient still air temperature of + 20°C				
	Thermal conductivity at +40°C (in W/(m.K))				
	0.025	0.030	0.035	0.040	0.045
	Thickness of insulation (in mm)				
10	17	18	19	20	27
12	18	19	20	21	29
15	18	19	21	29	31
22	20	29	30	32	33
28	21	30	32	34	35
35	22	32	34	35	37
42	22	33	35	37	39
54	23	35	37	39	40
Flat surfaces	29	31	34	36	38

**Table 13** *Economic thickness of insulation for domestic central heating installations in unheated areas*

Outside diameter of copper pipe (in mm)	Water temperature of +75°C with ambient still air temperature of -1°C				
	Thermal conductivity at +40°C (in W/(m.K))				
	0.025	0.030	0.035	0.040	0.045
	Thickness of insulation (in mm)				
10	19	20	21	32	34
12	20	21	22	32	34
15	21	22	32	33	35
22	22	32	34	35	36
28	23	34	36	36	36
35	24	35	37	38	39
42	25	37	38	39	40
54	26	37	38	39	40
Flat surfaces	34	37	40	43	45

## TABLES REPRODUCED FROM BS 5422: 1990

**Table 14 Economic thickness of insulation for domestic hot water systems in heated areas**

Outside diameter of copper pipe (in mm)	Water temperature of +60°C with ambient still air temperature of + 20°C				
	Thermal conductivity at +40°C (in W/(m.K))				
	0.025	0.030	0.035	0.040	0.045
	Thickness of insulation (in mm)				
10	13	14	14	14	15
12	13	14	14	15	16
15	13	14	14	16	17
22	14	15	16	17	18
28	14	15	16	18	19
35	15	17	17	19	19
42	15	17	18	19	20
54	16	18	19	20	21
Flat surfaces	20	22	24	24	25

**Table 15 Economic thickness of insulation for domestic hot water systems in unheated areas**

Outside diameter of copper pipe (in mm)	Water temperature of +60°C with ambient still air temperature of -1°C				
	Thermal conductivity at +40°C (in W/(m.K))				
	0.025	0.030	0.035	0.040	0.045
	Thickness of insulation (in mm)				
10	14	15	16	17	18
12	15	16	17	18	19
15	15	17	17	19	19
22	16	18	20	20	21
28	17	19	20	21	30
35	18	20	21	22	31
42	19	20	22	23	32
54	20	21	23	33	34
Flat surfaces	23	25	25	29	31

**TABLES REPRODUCED FROM BS 5422: 1990**

**Table 16 Economic thickness of insulation for process pipework and equipment**

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)														
	+100					+200					+300				
	Thermal conductivity at mean temperature (in W/(m.K))														
	0.02	0.03	0.04	0.05	0.06	0.03	0.04	0.05	0.06	0.07	0.03	0.04	0.05	0.06	0.07
	Thickness of insulation (in mm)														
17.2	28	31	35	38	41	45	49	52	56	59	52	57	61	66	70
21.3	29	33	37	40	43	46	50	54	58	62	55	60	65	70	74
26.9	31	35	39	43	46	50	54	59	63	67	59	64	69	74	78
33.7	33	36	40	44	48	52	56	61	65	69	61	66	72	77	82
42.4	36	40	45	49	53	56	61	67	72	77	67	73	79	84	90
48.3	38	42	47	51	55	59	64	70	75	80	70	77	82	88	95
60.3	41	45	50	55	59	63	69	75	81	86	76	82	89	96	102
76.1	42	47	52	57	62	67	73	79	85	90	78	86	94	101	107
88.9	44	49	54	59	64	70	76	82	89	94	83	90	98	105	112
101.6	45	50	56	62	66	73	79	85	91	97	85	93	101	109	116
114.3	46	52	57	63	68	76	80	87	93	99	87	95	103	111	118
139.7	49	54	60	66	71	78	84	92	99	105	94	102	110	118	125
168.3	52	58	64	70	76	83	90	98	105	111	101	107	117	126	134
219.1	54	60	67	74	80	87	95	104	112	119	105	114	124	133	142
244.5	55	62	69	76	82	89	98	106	115	122	108	117	127	137	146
273	56	64	71	78	84	94	100	110	118	126	113	120	132	142	151
323.9	58	66	73	80	86	94	104	114	123	132	115	123	135	145	154
355.6	59	67	74	81	88	97	107	116	125	134	116	125	137	147	156
406.4	62	69	76	83	90	100	109	118	127	136	118	128	140	150	159
457	63	70	77	84	91	102	111	120	129	138	121	132	144	154	163
508	65	72	79	86	93	105	114	123	132	141	124	134	146	156	165
Over 508 and incl. flat surfaces	72	78	87	98	105	113	124	133	142	151	127	137	151	161	170

TABLES REPRODUCED FROM BS 5422: 1990

Table 16 Economic thickness of insulation for process pipework and equipment cont...

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)																			
	+400					+500					+600					+700				
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.04	0.05	0.06	0.07	0.08	0.05	0.06	0.07	0.08	0.09	0.06	0.07	0.08	0.09	0.10	0.07	0.08	0.09	0.10	0.11
	Thickness of insulation (in mm)																			
17.2	64	69	74	79	83	76	81	86	91	95	89	93	98	103	107	99	104	109	114	119
21.3	68	73	78	83	88	81	86	91	96	101	93	98	103	108	113	105	110	115	120	125
26.9	73	78	83	89	94	87	92	98	103	107	100	105	110	115	120	113	118	123	128	133
33.7	76	81	87	92	97	89	95	100	106	111	103	108	114	119	124	116	121	127	132	137
42.4	83	89	96	102	107	99	105	111	117	123	114	120	126	132	137	128	134	140	146	152
48.3	87	93	100	106	112	103	109	116	122	128	119	125	132	138	143	134	140	146	152	158
60.3	94	101	108	115	121	111	118	125	132	138	128	135	142	149	156	144	151	158	165	172
76.1	99	106	114	121	127	117	124	132	139	146	135	142	149	156	163	152	159	166	173	180
88.9	103	110	118	126	133	123	130	138	145	152	141	148	156	163	170	159	166	174	181	189
101.6	106	114	123	130	138	126	134	142	150	157	145	153	161	169	177	164	172	180	187	195
114.3	109	116	125	133	140	129	137	145	153	160	149	157	165	173	181	167	175	183	191	198
139.7	116	124	133	141	149	138	146	155	163	171	158	167	175	184	190	179	187	195	204	211
168.3	124	132	142	151	159	147	156	165	174	182	170	178	188	196	205	191	200	209	218	227
219.1	130	140	151	161	171	156	166	176	186	195	180	190	200	210	220	203	213	223	233	243
244.5	135	145	156	165	175	161	171	182	192	201	186	196	206	216	226	210	220	230	240	250
273	139	149	160	170	180	166	176	188	198	207	191	202	213	224	235	217	227	238	248	258
323.9	142	153	164	174	184	171	181	193	202	212	196	207	218	229	240	223	233	244	254	264
355.6	146	157	168	178	188	177	185	197	206	216	201	212	224	235	245	230	240	251	261	271
406.4	149	160	171	181	192	181	189	202	213	223	207	218	230	241	252	234	245	257	269	279
457	153	165	176	187	198	187	196	209	220	231	213	225	238	250	261	242	254	266	278	289
508	155	168	179	191	202	191	200	213	226	237	218	231	244	256	267	248	260	273	285	296
Over 508 and incl. flat surfaces	158	171	182	195	205	194	207	218	230	239	228	240	250	261	270	257	271	279	293	304

Note: For thicknesses in bold type, the outside surface temperature is likely to exceed 50°C if a low emissivity surface is used, i.e. bright metal

TABLES REPRODUCED FROM BS 5422: 1990

*Table 17 Fuel cost comparisons: cost of heat related to fuel price*

Cost of heat	Fuel oil at 70% efficiency	Natural gas at 70% efficiency	Solid fuel at 55% efficiency	Solid fuel at 70% efficiency	Electricity at 100% efficiency
pence/useful MJ	pence/l	pence/therm	£/t	£/t	pence/kWh
0.30	7.89	22.16	38.4	58.61	1.08
0.40	10.52	29.54	51.2	78.15	1.44
0.50	13.15	36.93	64.0	97.68	1.80
0.56	14.73	41.36	71.7	109.40	2.02
0.60	15.78	44.31	76.8	117.22	2.16
0.64	16.83	47.27	81.9	125.03	2.30
0.68	17.88	50.22	87.0	132.85	2.49
0.72	18.94	53.18	92.1	140.66	2.59
0.76	19.99	56.13	97.2	148.48	2.74
0.80	21.04	59.08	102.4	156.29	2.88
0.84	22.09	62.04	107.5	164.11	3.02
0.88	23.14	65.00	112.6	171.92	3.17
0.92	24.20	67.96	117.7	174.74	3.31
0.96	25.25	70.91	122.8	187.55	3.46
1.00	26.30	73.87	128.0	195.37	3.60
1.04	27.35	76.82	133.1	203.18	3.74
1.08	28.40	79.77	133.2	203.66	3.89
1.12	29.46	82.73	143.3	218.81	4.03
1.16	30.51	85.68	148.4	226.67	4.18
1.20	31.56	88.64	153.5	234.44	4.32

*NOTE 1: The first column shows the basic costs required for economic thickness calculations. The range covers both past prices and possible future price increases.*

*NOTE 2: The efficiencies given in the column headings indicate the values assumed in the calculations; they do not represent the actual operating efficiency. In practice the system efficiency for a particular application may be considerably lower than the values given.*

This Table is based on Table 36 in BS 5422: 1990. The column headed 'Fuel oil at 70% efficiency' has been recalculated and is not taken from the British Standard. Copies of the original document can be obtained by post from British Standards Institution, Sales Department, Linford Wood, Milton Keynes, MK14 6LE.

## **APPENDIX 3**

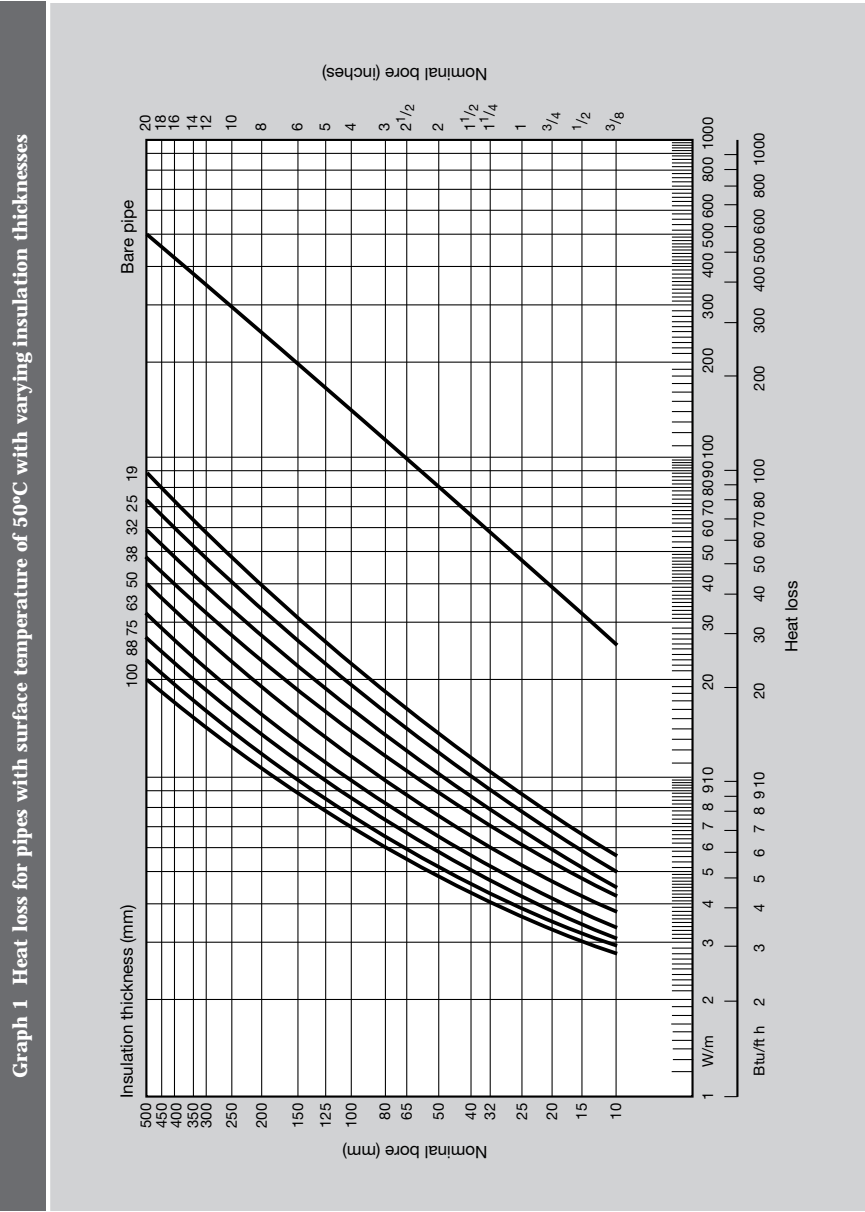
---

### **HEAT LOSS GRAPHS FOR VARIOUS MATERIALS AND SURFACE TEMPERATURES**

A wide variety of pipe insulation products is available from many different companies. The heat loss graphs are based on four common product types, which are given below.

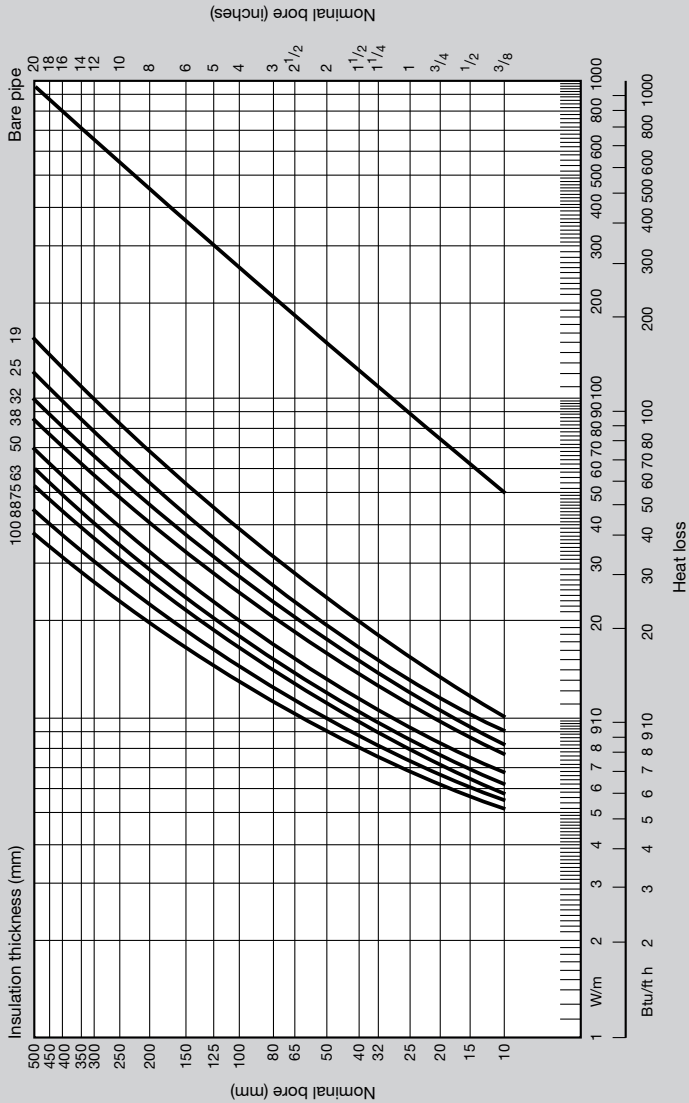
- Preformed rigid fibrous sections (including rock and glass fibres) (Graphs 1-10)
- Preformed rigid calcium silicate or (up to 300°C) 85% magnesia sections. (Graphs 11 - 20)
- Preformed rigid polyisocyanurate or (up to 100°C) polyurethane sections (Graphs 21 - 23)
- Preformed expanded nitrile rubber and polyethylene foam sections (Graphs 24 - 25)

PREFORMED RIGID FIBROUS SECTIONS



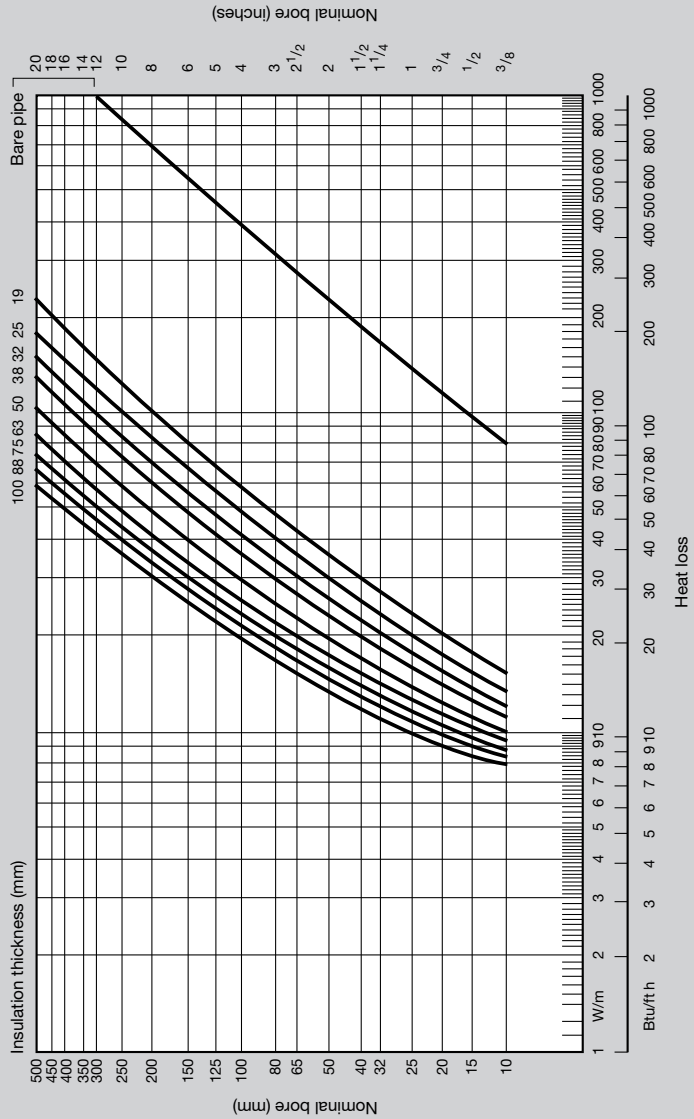
PREFORMED RIGID FIBROUS SECTIONS

Graph 2 Heat loss for pipes with surface temperature of 75°C with varying insulation thicknesses



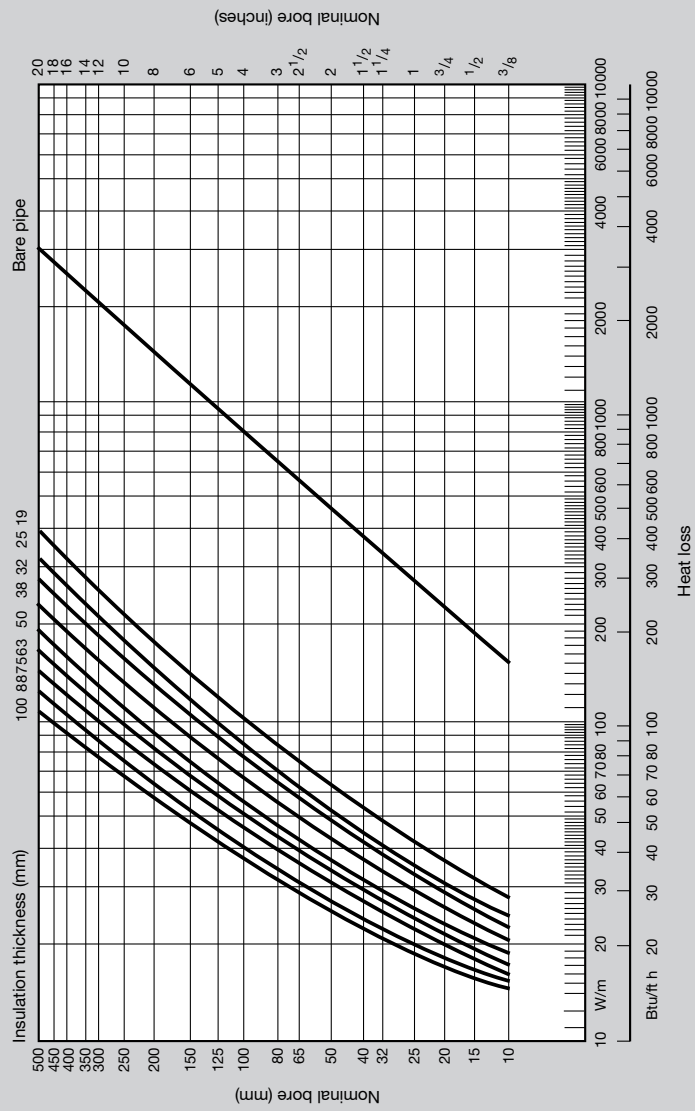
PREFORMED RIGID FIBROUS SECTIONS

Graph 3 Heat loss for pipes with surface temperature of 100°C with varying insulation thicknesses



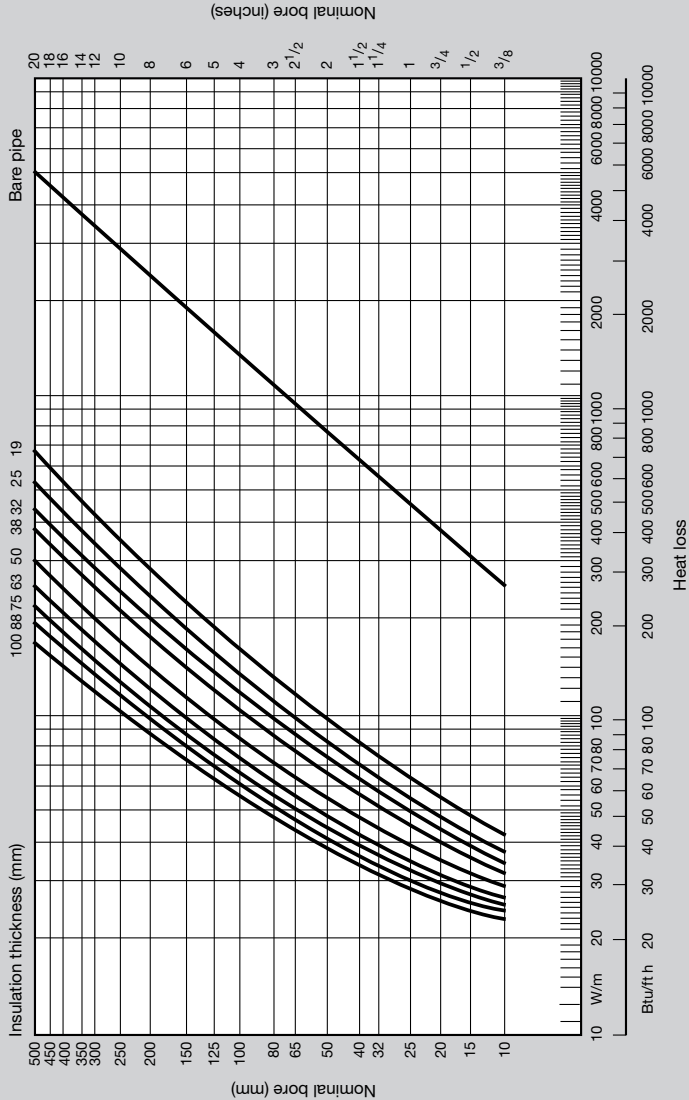
PREFORMED RIGID FIBROUS SECTIONS

Graph 4 Heat loss for pipes with surface temperature of 150°C with varying insulation thicknesses



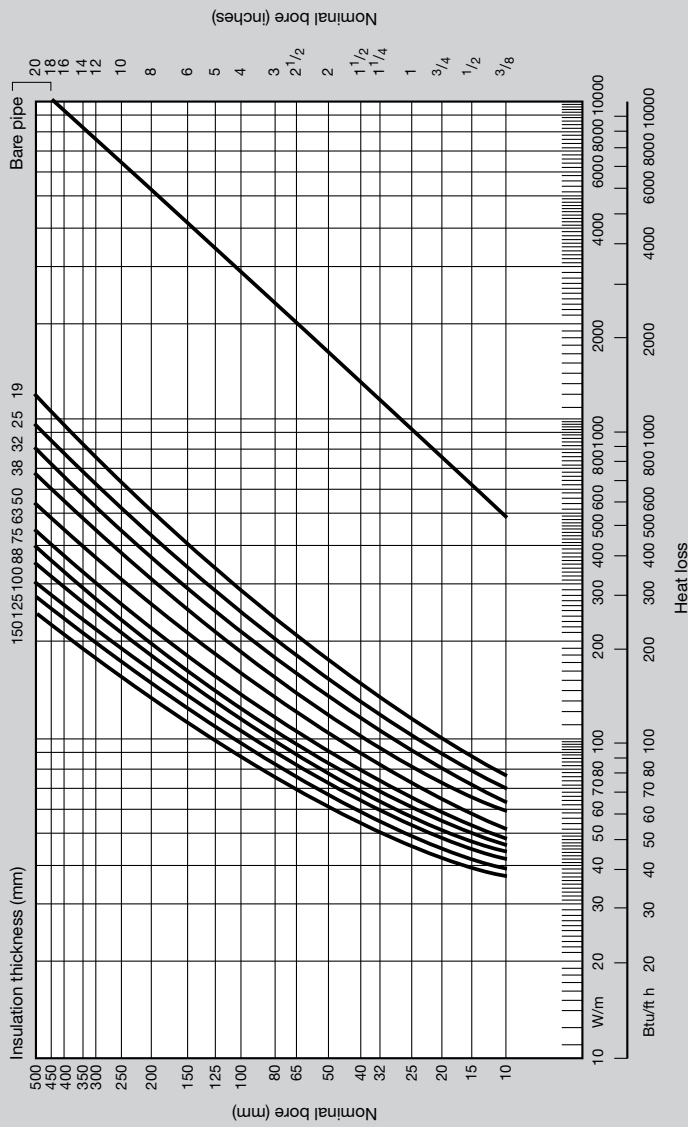
PREFORMED RIGID FIBROUS SECTIONS

Graph 5 Heat loss for pipes with surface temperature of 200°C with varying insulation thicknesses

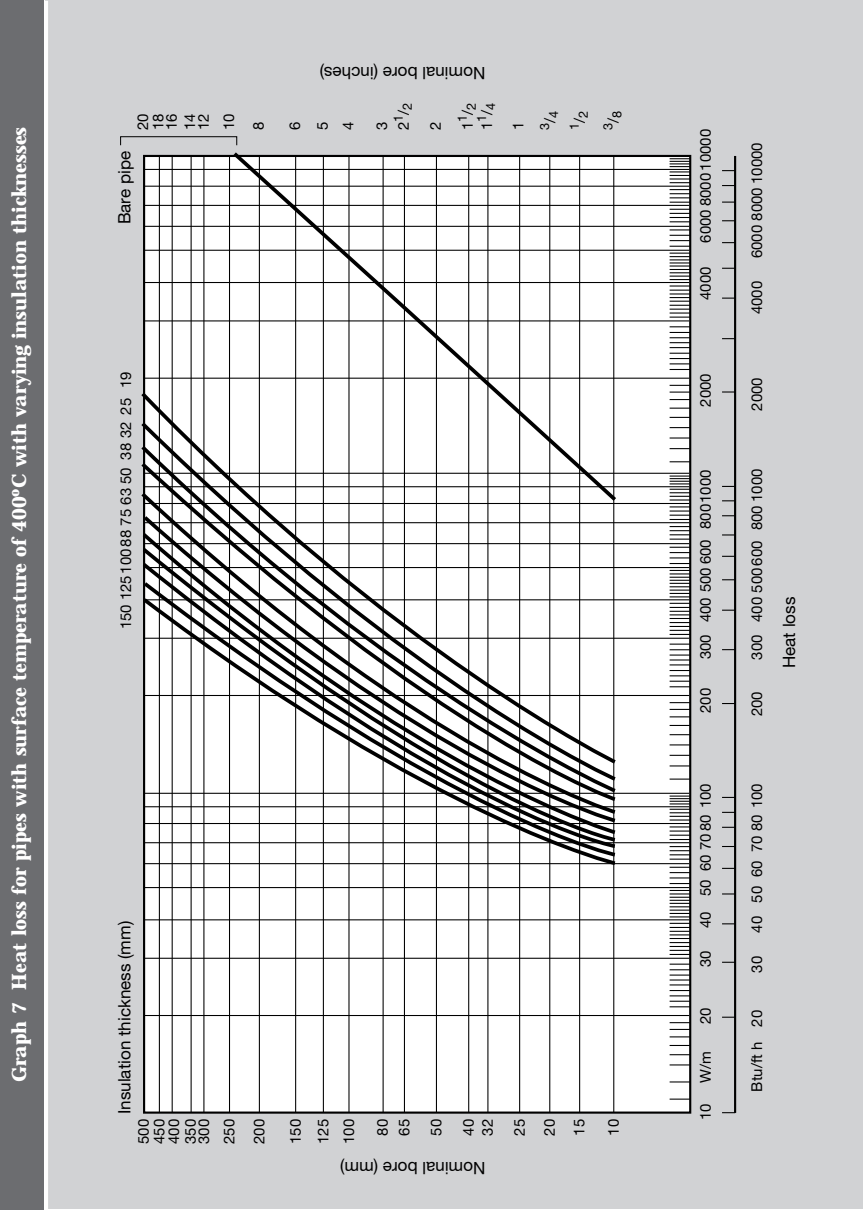


PREFORMED RIGID FIBROUS SECTIONS

Graph 6 Heat loss for pipes with surface temperature of 300°C with varying insulation thicknesses

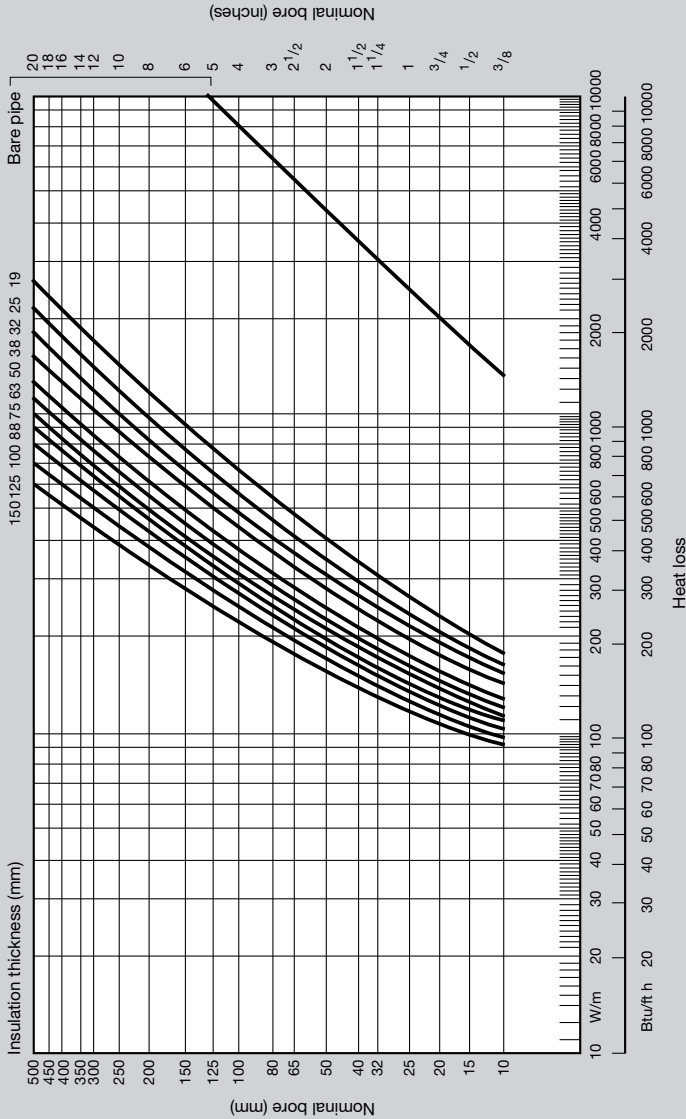


PREFORMED RIGID FIBROUS SECTIONS

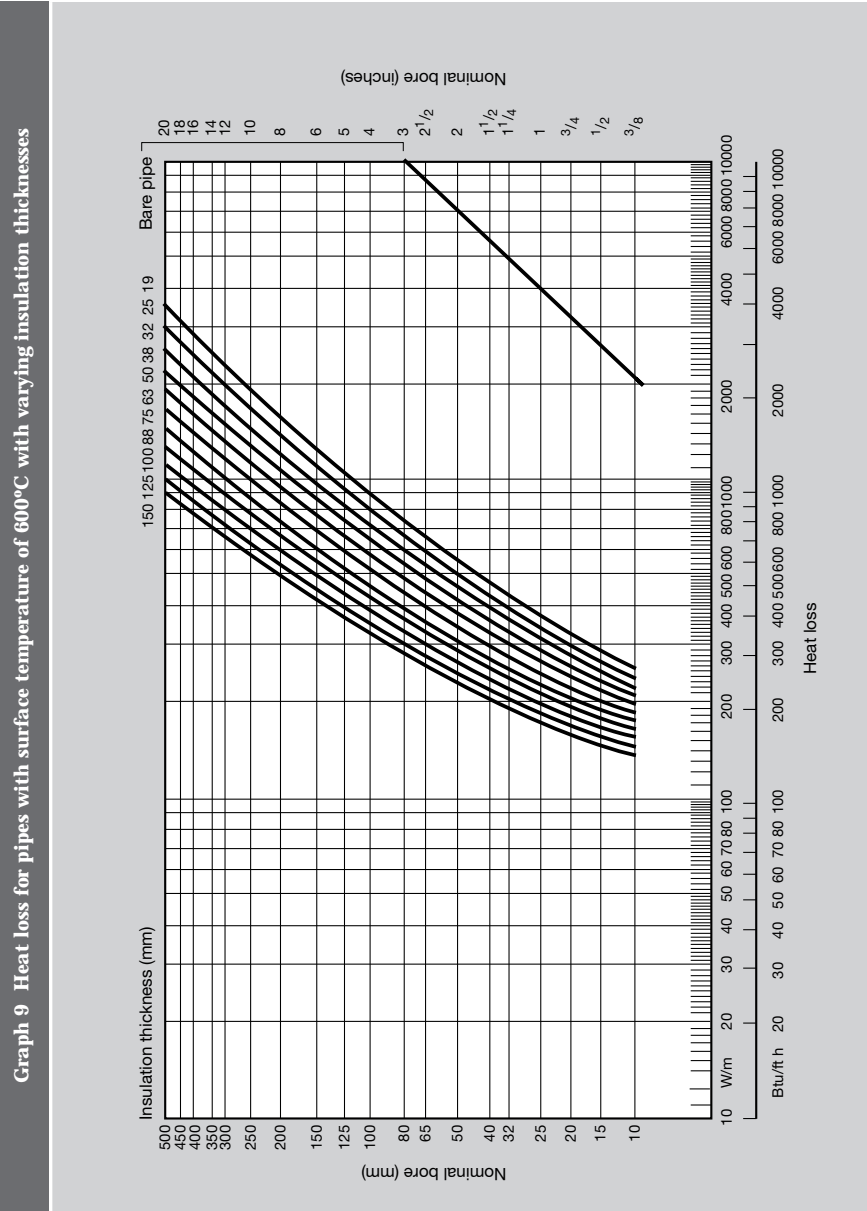


# PREFORMED RIGID FIBROUS SECTIONS

Graph 8 Heat loss for pipes with surface temperature of 500°C with varying insulation thicknesses

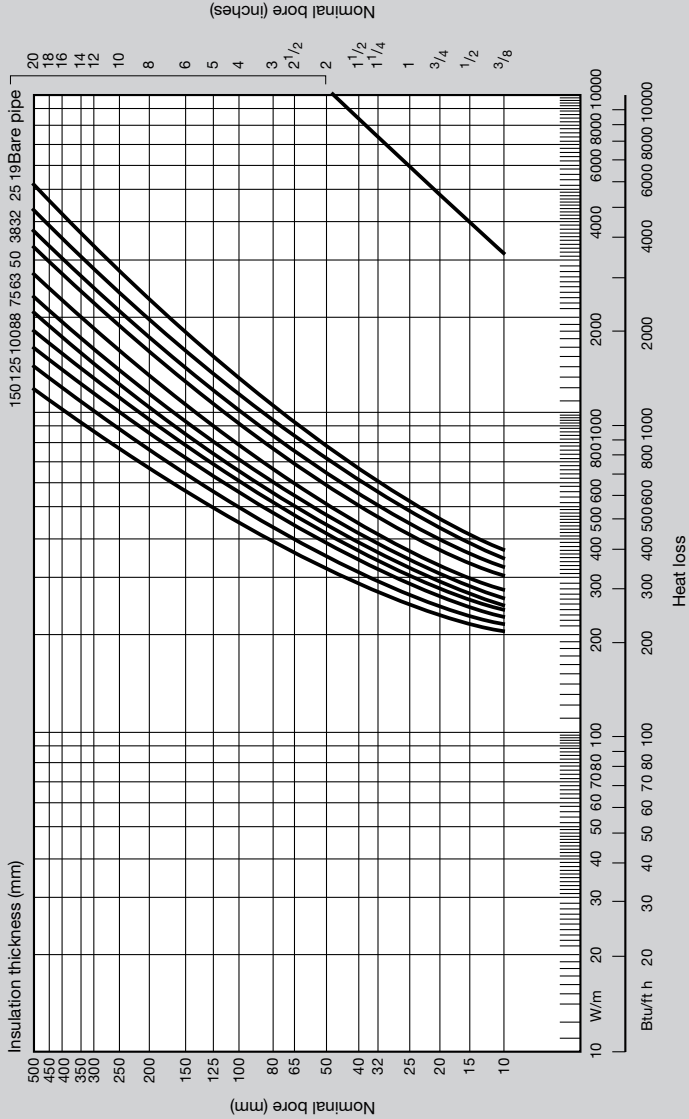


PREFORMED RIGID FIBROUS SECTIONS

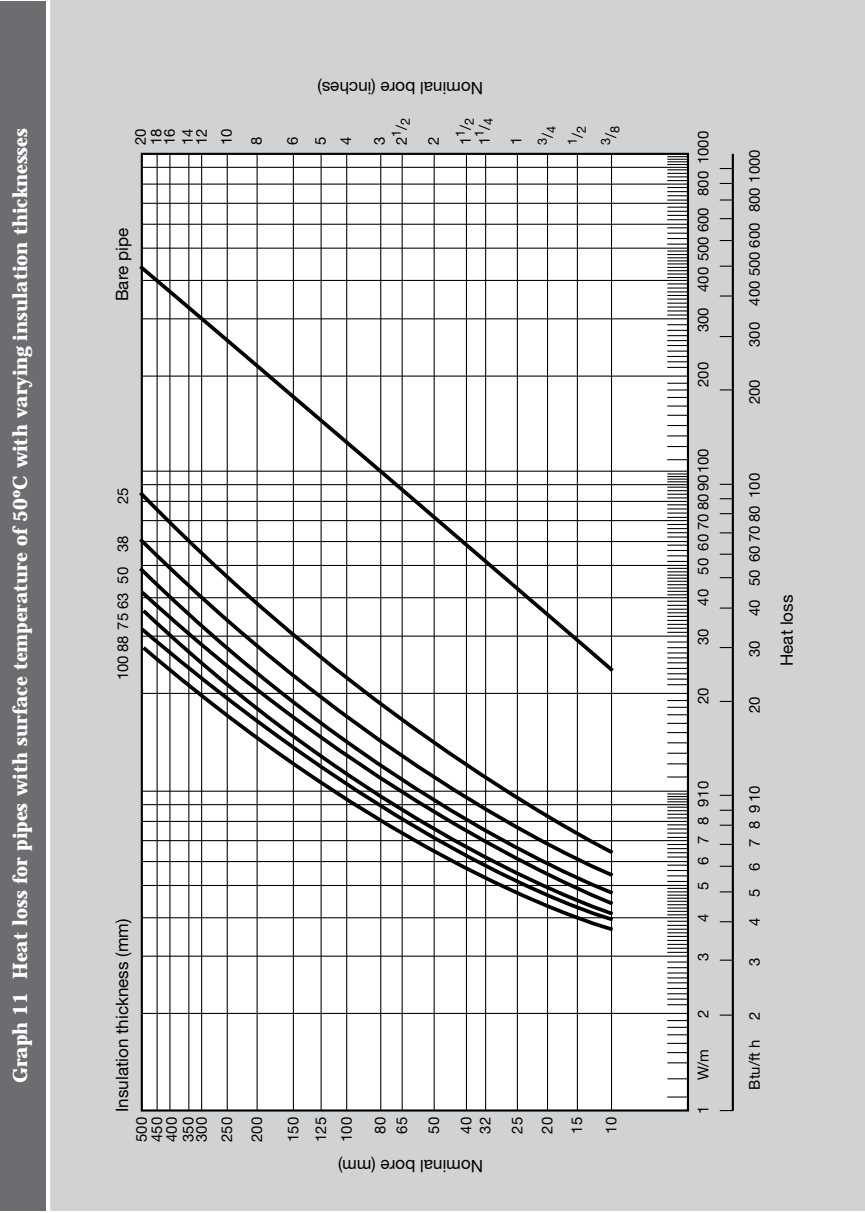


PREFORMED RIGID FIBROUS SECTIONS

Graph 10 Heat loss for pipes with surface temperature of 700°C with varying insulation thicknesses

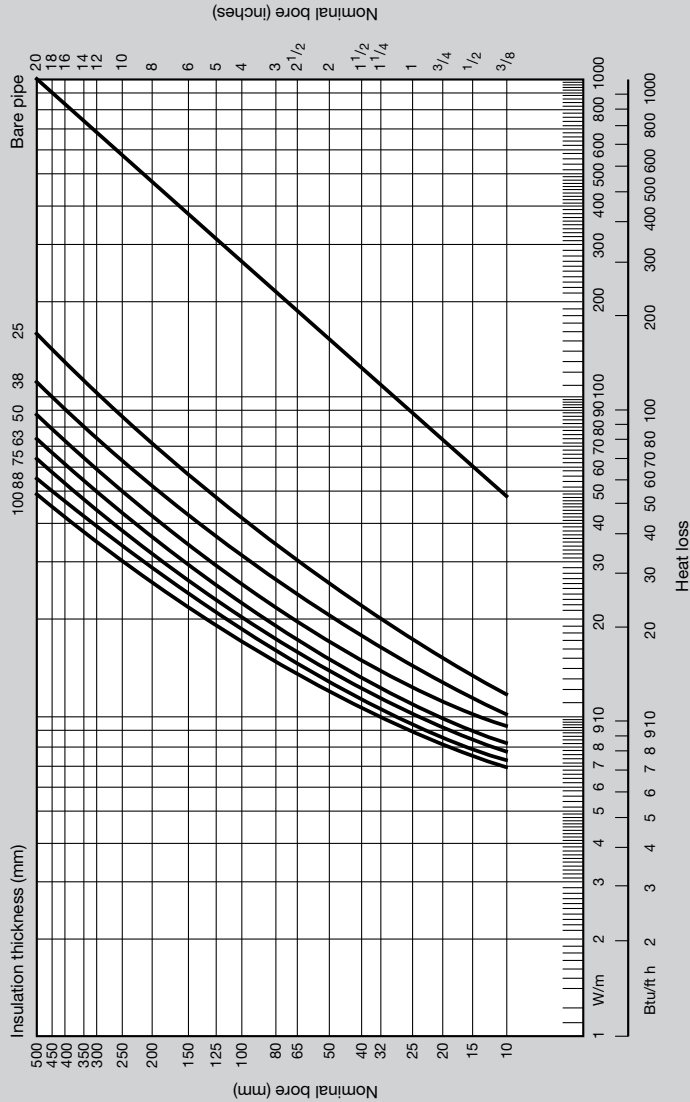


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

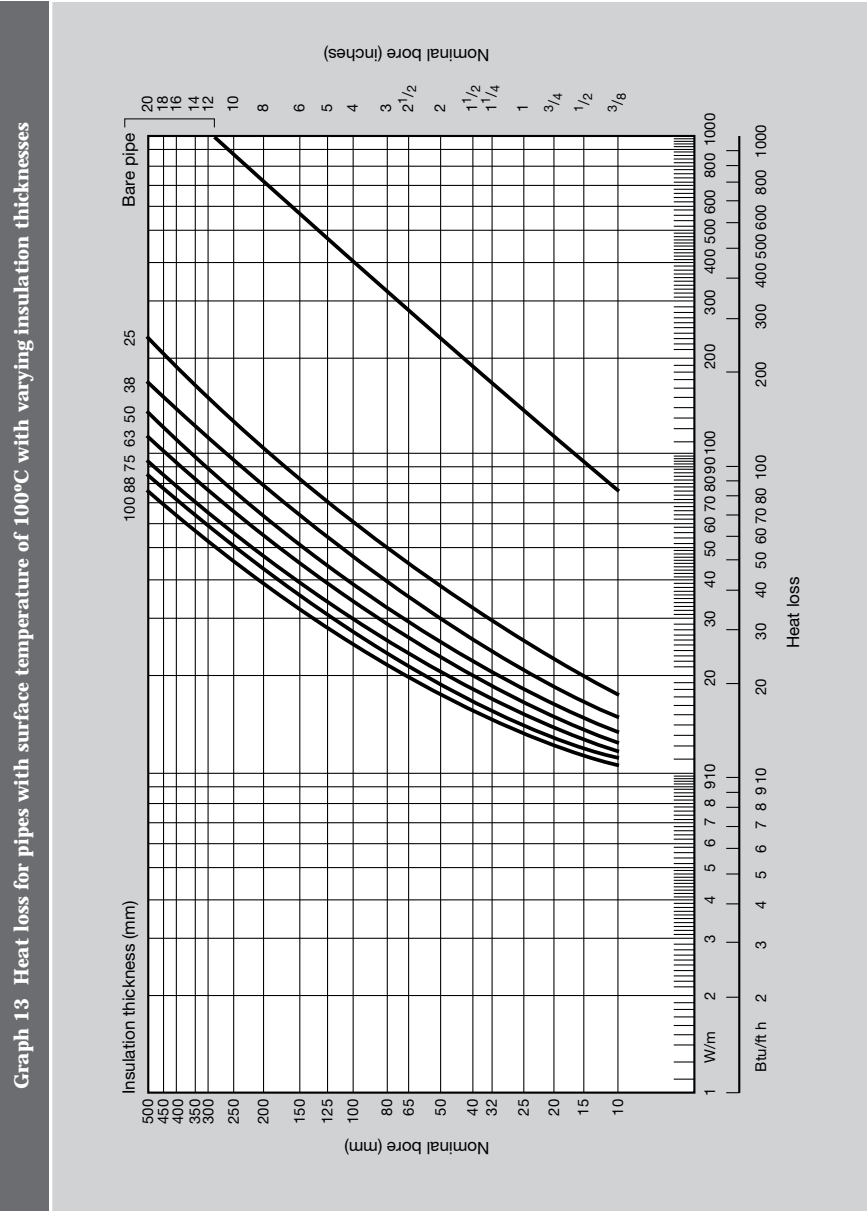


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 12 Heat loss for pipes with surface temperature of 75°C with varying insulation thicknesses

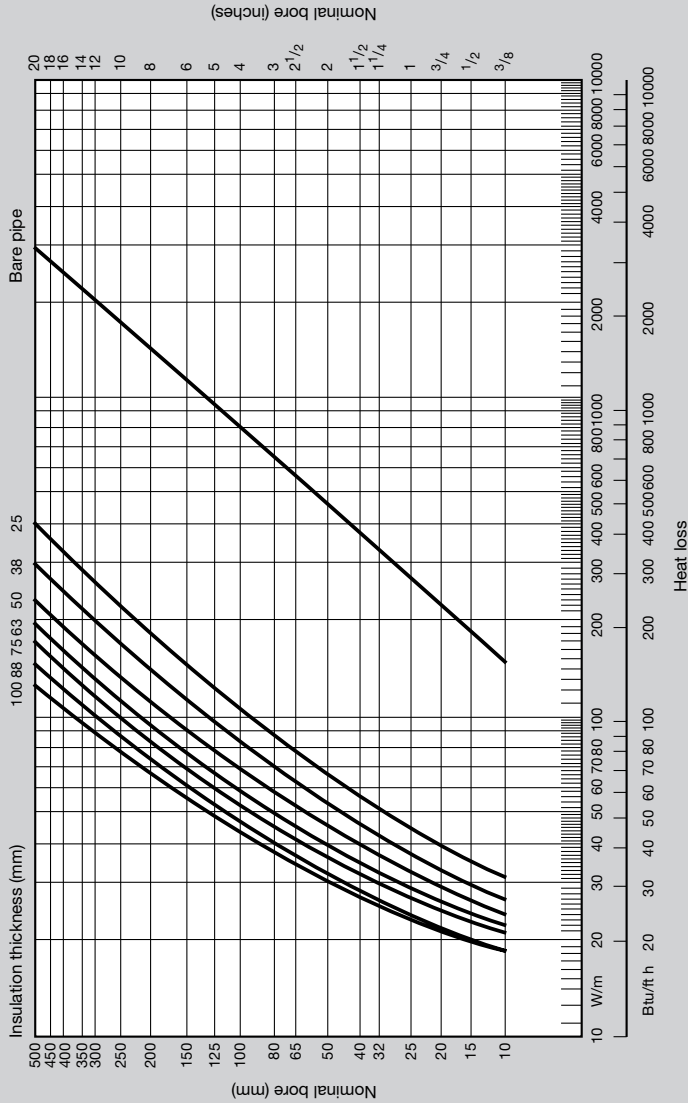


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS



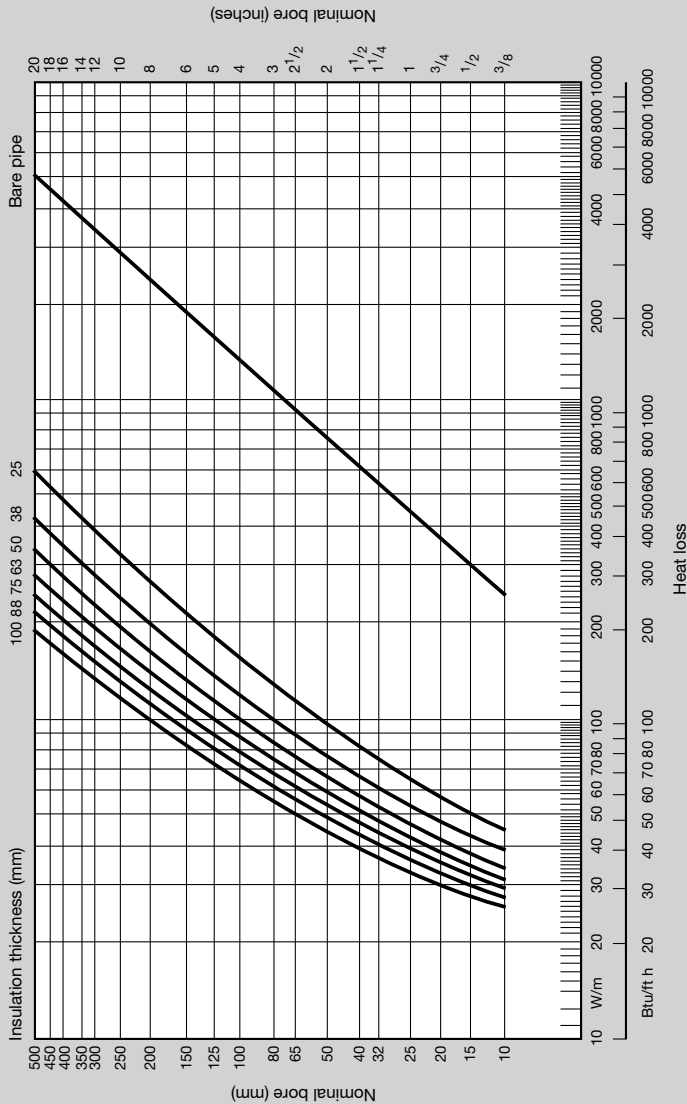
PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 14 Heat loss for pipes with surface temperature of 150°C with varying insulation thicknesses



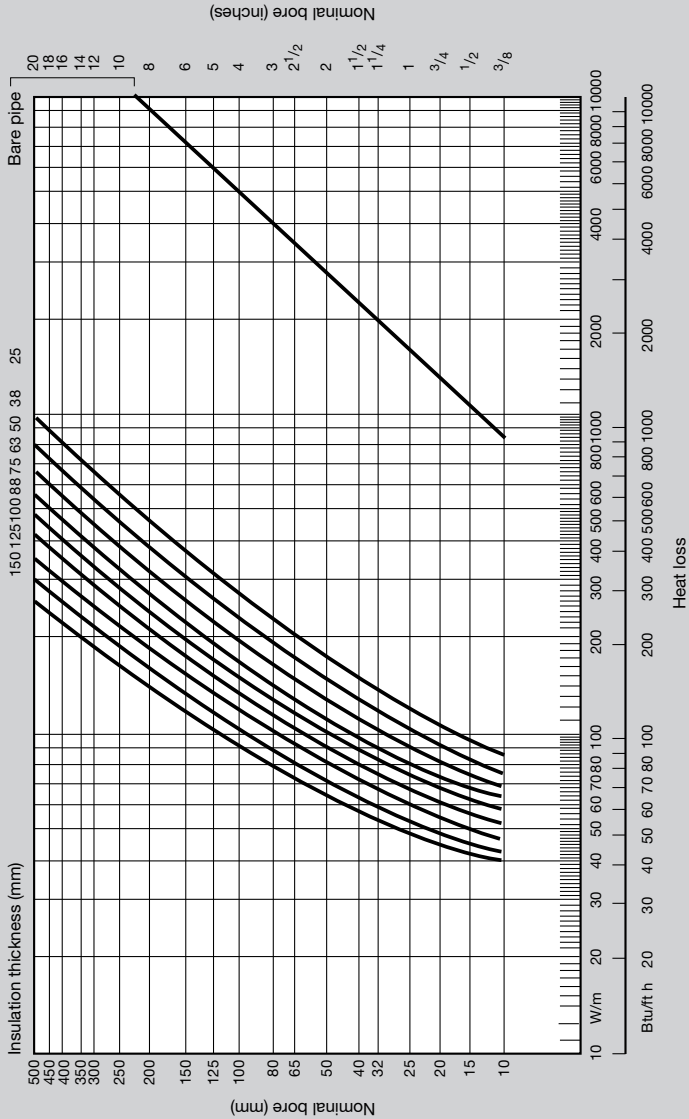
PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 15 Heat loss for pipes with surface temperature of 200°C with varying insulation thicknesses

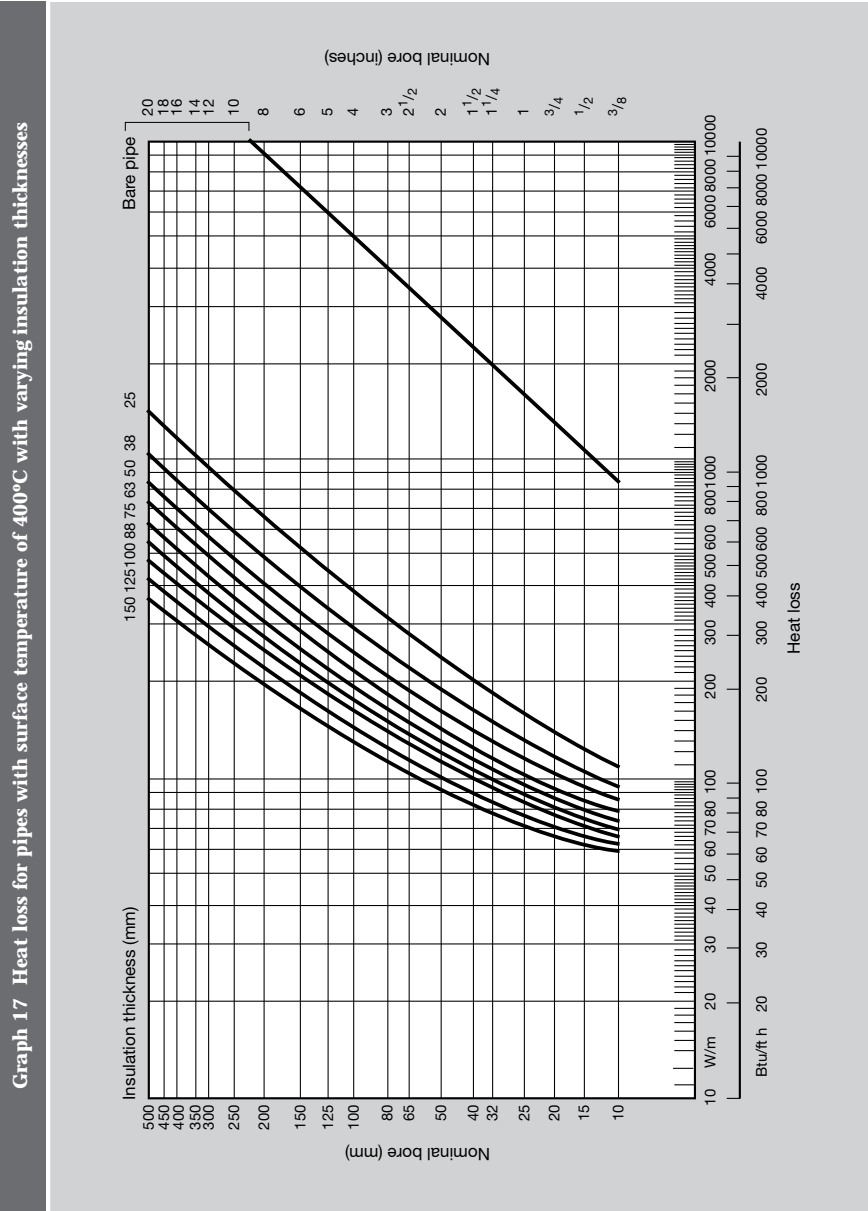


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 16 Heat loss for pipes with surface temperature of 300°C with varying insulation thicknesses

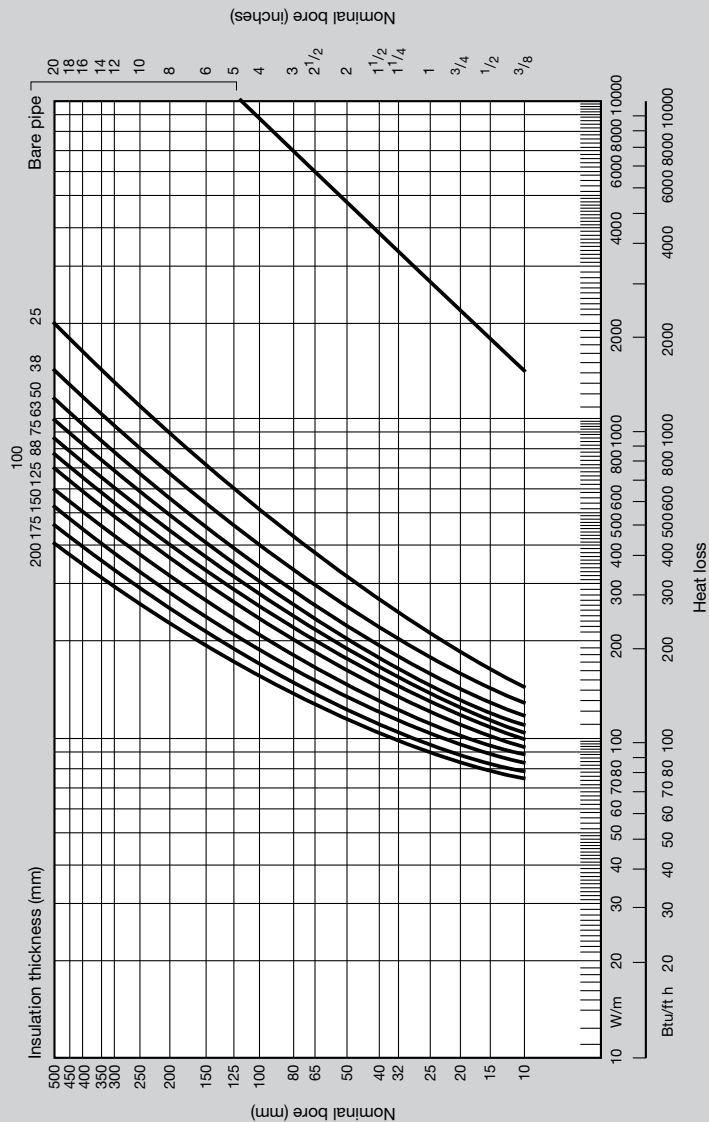


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

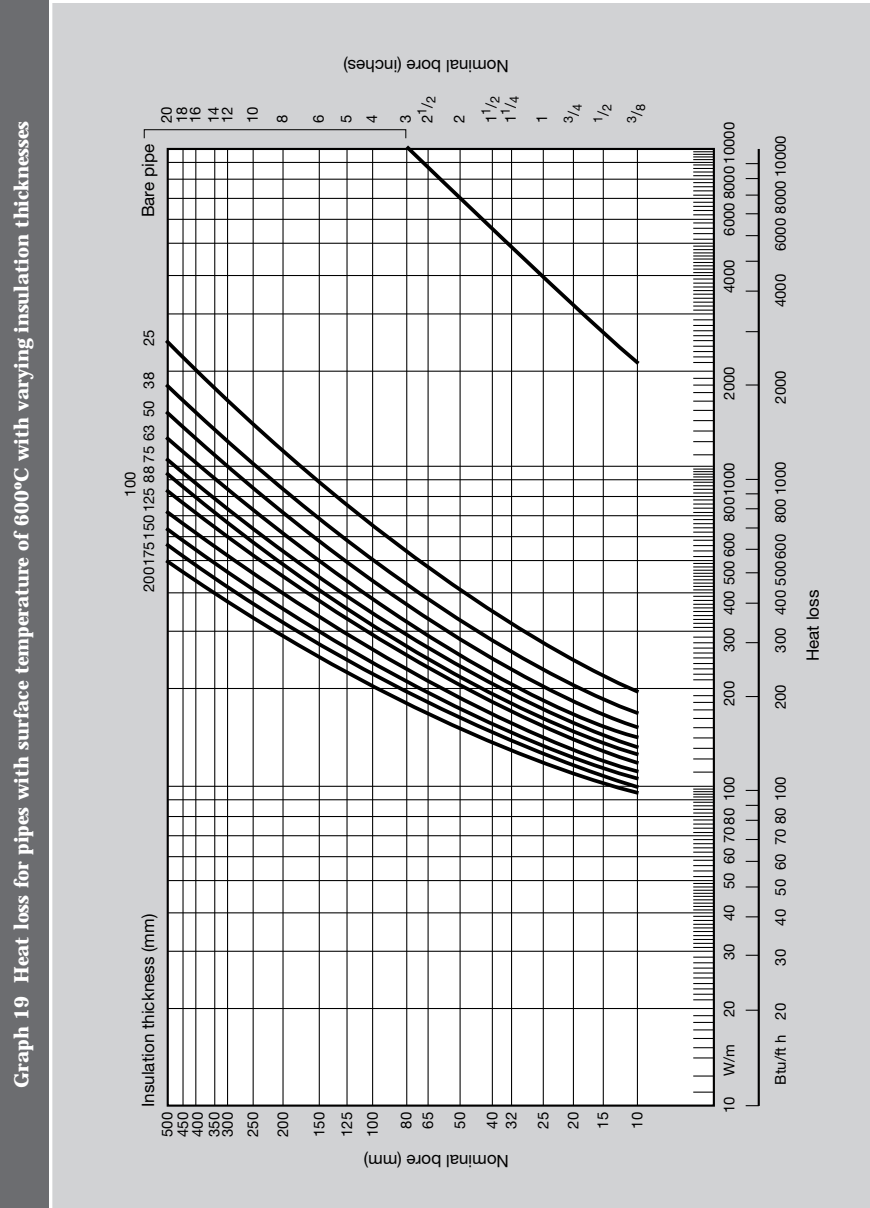


## PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 18 Heat loss for pipes with surface temperature of 500°C with varying insulation thicknesses

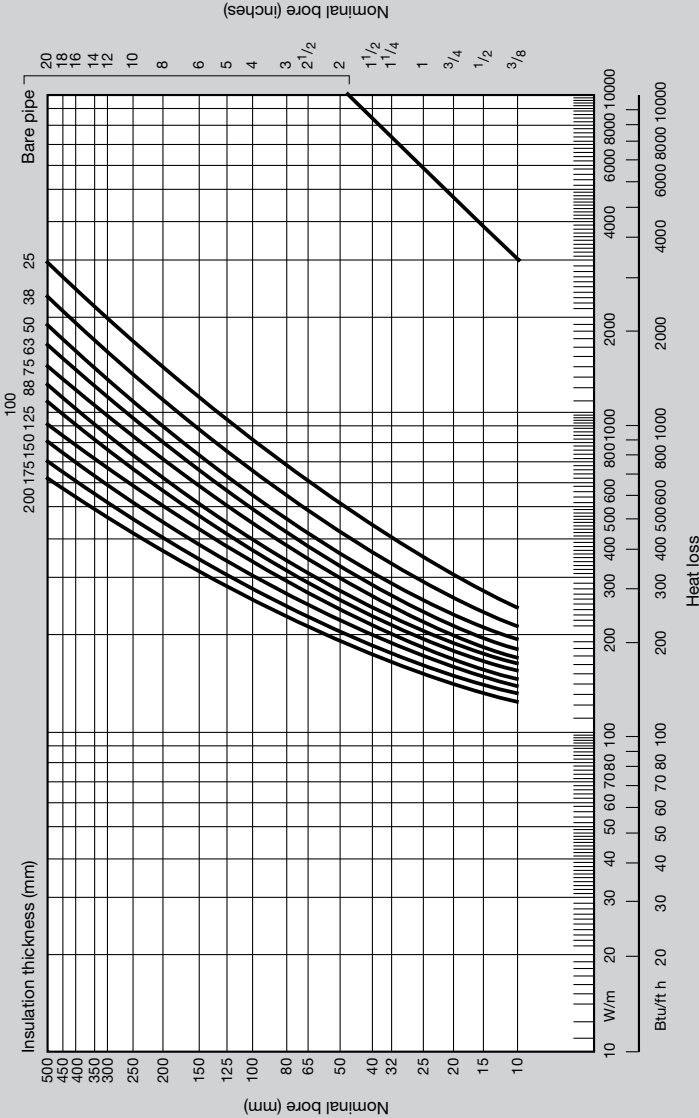


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

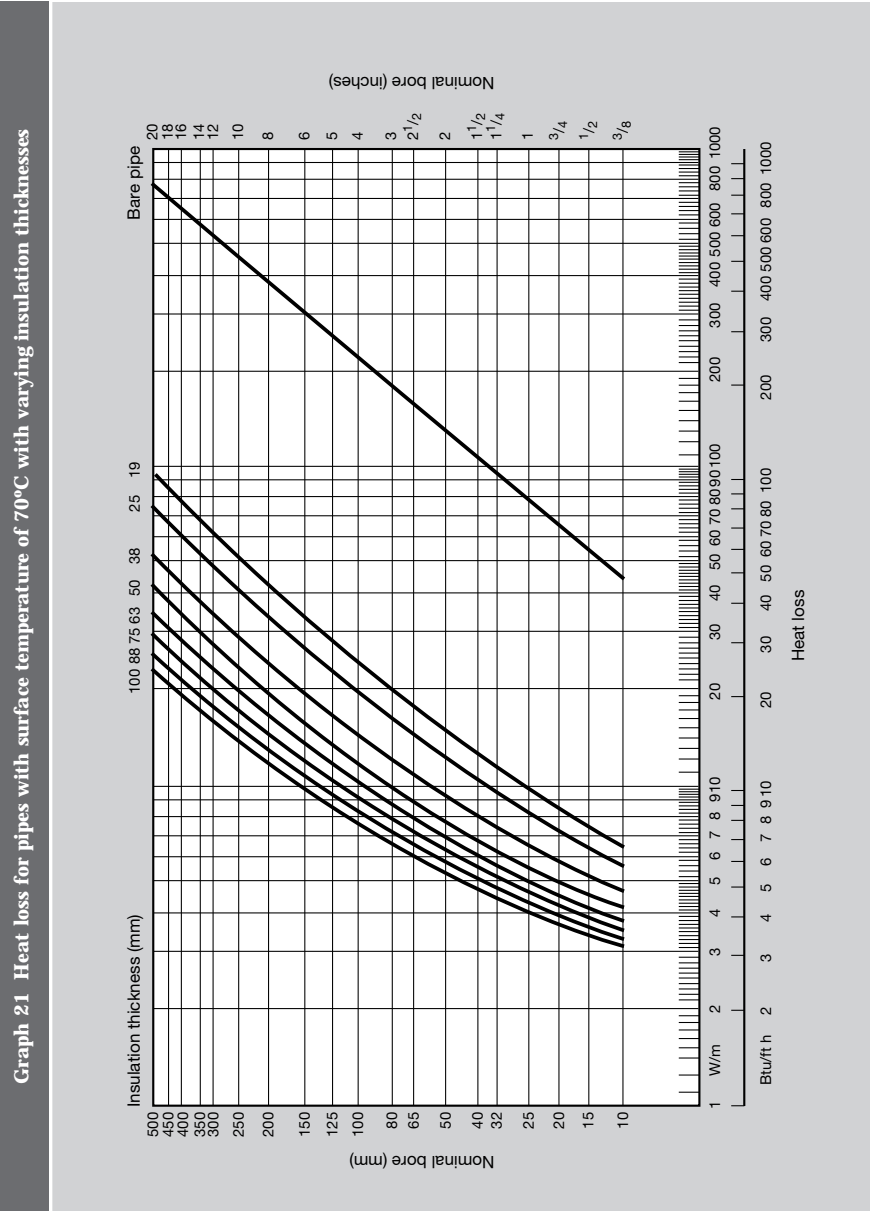


PREFORMED RIGID CALCIUM SILICATE OR 85% MAGNESIA SECTIONS

Graph 20 Heat loss for pipes with surface temperature of 700°C with varying insulation thicknesses

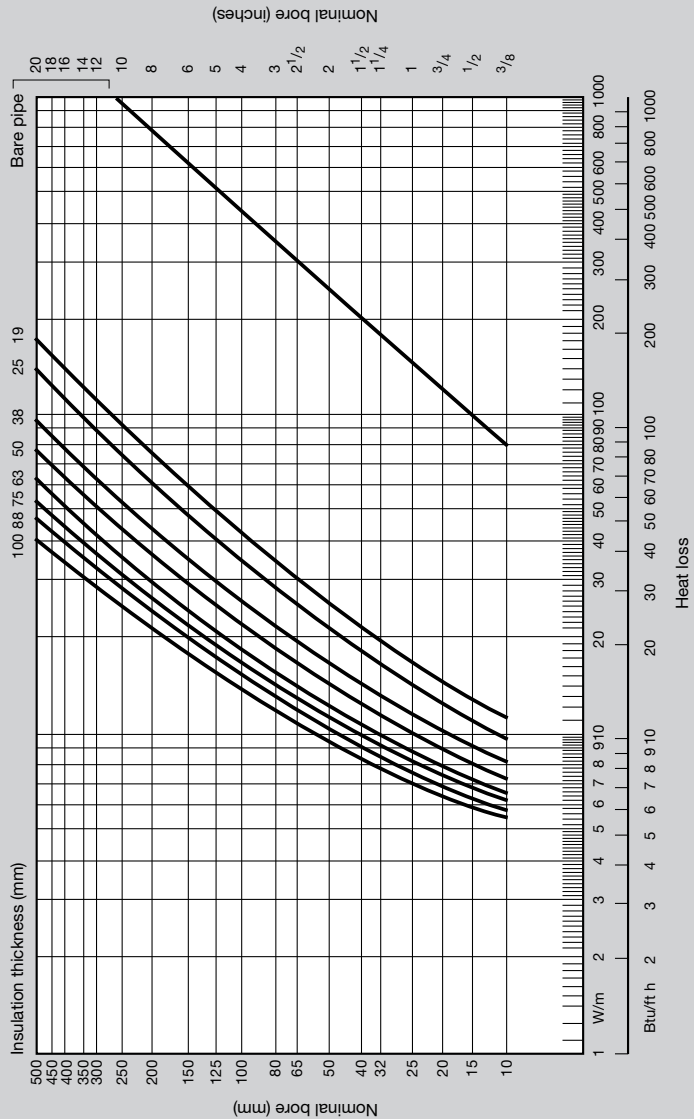


PREFORMED RIGID POLYISOCYANURATE OR POLYURETHANE SECTIONS

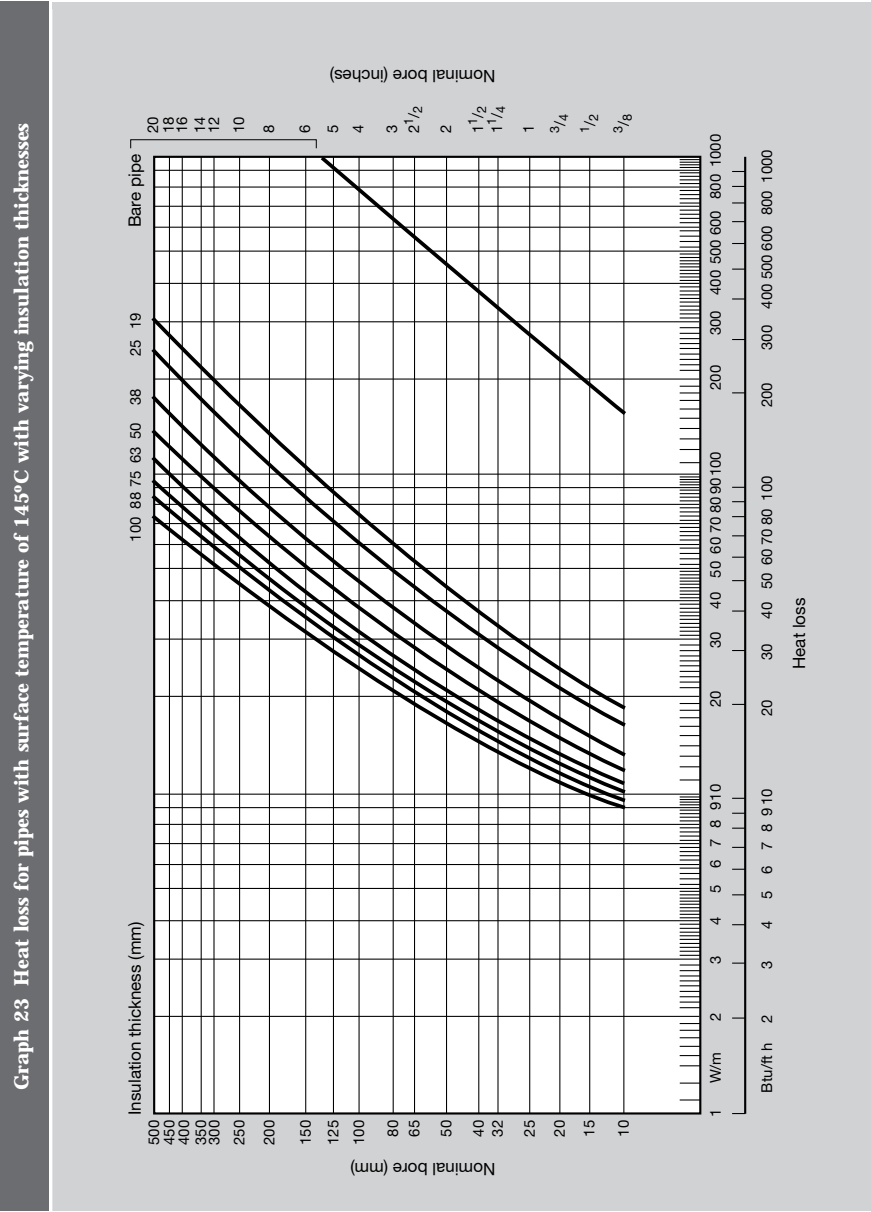


PREFORMED RIGID POLYISOCYANURATE OR POLYURETHANE SECTIONS

Graph 22 Heat loss for pipes with surface temperature of 100°C with varying insulation thicknesses

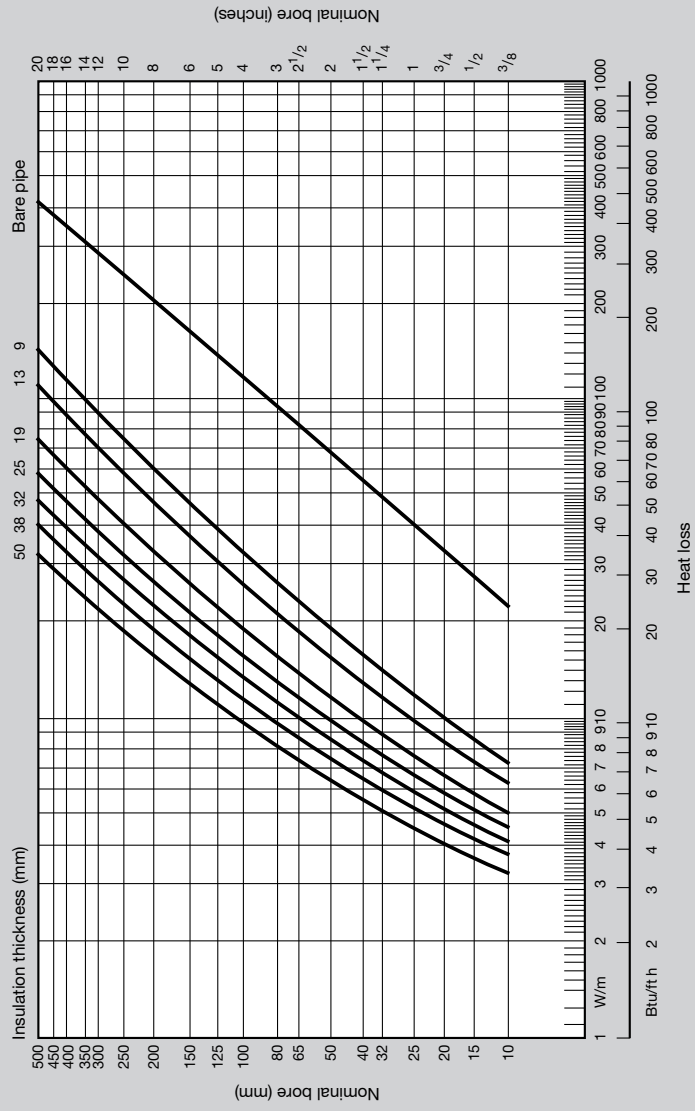


PREFORMED RIGID POLYISOCYANURATE OR POLYURETHANE SECTIONS

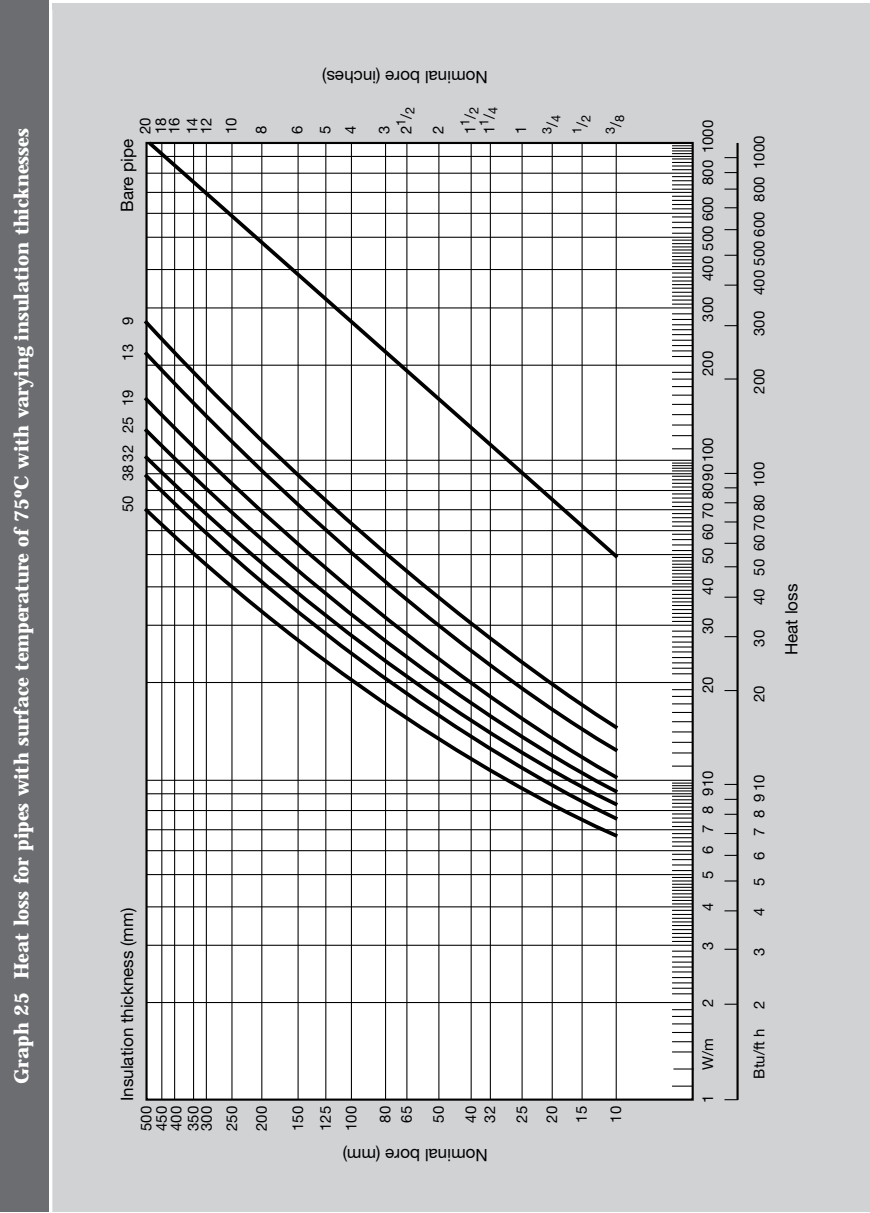


PREFORMED EXPANDED NITRILE RUBBER AND POLYETHYLENE FOAM SECTIONS

Graph 24 Heat loss for pipes with surface temperature of 50°C with varying insulation thicknesses



PREFORMED EXPANDED NITRILE RUBBER AND POLYETHYLENE FOAM SECTIONS



## APPENDIX 4 SOME BASIC HEAT TRANSFER FORMULAE

### SOME BASIC HEAT TRANSFER FORMULAE

The various methods of estimating the economic thickness of insulation have made reasonable assumptions about the ambient conditions. Since these can have a significant effect on the rate of heat loss, any serious divergence from the assumed conditions should be analysed as an individual case. This requires the use of basic heat transfer equations. There are many standard texts on heat transfer which give

$$Q = U (t_1 - t_m) \dots A1$$

complete details but the basic equations are:

$$\frac{1}{U} = \frac{1}{3.142 d_i h} + \frac{\ln (r_i / r_o)}{6.284 k} \dots A2$$

and

Where:

Q = heat loss per metre length of pipe (W/m)

U = Overall heat transfer coefficient (W/m<sup>2</sup>)

t<sub>1</sub> = pipe surface temperature (°C) -

approximately equal to process stream temperature

t<sub>2</sub> = outside temperature of insulation

t<sub>m</sub> = ambient temperature (°C)

r<sub>i</sub> = radius of outer surface of insulation (m)

r<sub>o</sub> = outer radius of pipe (m)

d<sub>i</sub> = diameter of outer surface of insulation (m)

h = surface heat transfer coefficient (W/m<sup>2</sup>K)

k = thermal conductivity of insulation (W/m.k)

These equations are used to find the heat loss per metre length of pipe. The overall heat transfer coefficient, U, is determined first by solving equation A2. Equation A1 then gives the required value. The problem is determining a suitable value for h, the surface heat transfer coefficient. This can be done from first principles (see any standard text on the subject) or Table 22 can be used to give an approximate value.

**Table 22 Variation of outer surface coefficient with temperature difference between surface and air for various outer dimensions of insulation**

Outer diameter insulation (in mm)	High emissivity surface				Low emissivity surface			
	Temperature difference (t <sub>2</sub> - t <sub>m</sub> ) (in K)							
	1	2	5	10	1	2	5	10
	Outer surface coefficient, h (in W/(m <sup>2</sup> .K))							
40	8.0	8.4	9.1	9.7	3.4	3.9	4.7	5.4
60	7.6	8.0	8.7	9.3	3.1	3.5	4.2	4.9
100	7.3	7.7	8.3	8.8	2.7	3.1	3.8	4.4
200	7.0	7.4	7.9	8.4	2.4	2.8	3.4	4.0
Vertical flat surface	6.6	7.0	7.5	8.0	2.0	2.4	3.0	3.6

NOTE: The above figures refer to the outer surface of the insulation

**Titles in the Fuel Efficiency Booklet series are:**

- 1 *Energy audits for industry*
- 1B *Energy audits for buildings*
- 2 *Steam*
- 3 *Economic use of fired space heaters for industry and commerce*
- 4 *Compressed air and energy use*
- 7 *Degree days*
- 8 *The economic thickness of insulation for hot pipes*
- 9 *Economic use of electricity in industry*
- 9B *Economic use of electricity in buildings*
- 10 *Controls and energy savings*
- 11 *The economic use of refrigeration plant*
- 12 *Energy management and good lighting practices*
- 13 *Waste avoidance methods*
- 14 *Economic use of oil-fired boiler plant*
- 15 *Economic use of gas-fired boiler plant*
- 16 *Economic thickness of insulation for existing industrial buildings*

- 17 *Economic use of coal-fired boiler plant*
- 19 *Process plant insulation and fuel efficiency*
- 20 *Energy efficiency in road transport*

Fuel Efficiency booklets are part of the Energy Efficiency Best Practice programme, an initiative aimed at advancing and promoting ways of improving the efficiency with which energy is used in the UK.

For copies of Fuel Efficiency booklets or further information please contact the addresses below.

Overseas customers please remit £3 per copy (minimum of £6) to the ETSU or BRECSU address with order to cover cost of packaging and posting. Please make cheques, drafts or money orders payable to ETSU or BRECSU, as appropriate.

**The Government's Energy Efficiency Best Practice Programme** provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

**Further information**

For buildings-related publications please contact:

Enquiries Bureau

**BRECSU**

Building Research Establishment  
Garston, Watford, WD2 7JR

Tel 01923 664258

Fax 01923 664787

E-mail [brecsuenq@bre.co.uk](mailto:brecsuenq@bre.co.uk)

For industrial and transport publications please contact:  
Energy Efficiency Enquiries Bureau

**ETSU**

Harwell, Didcot, Oxfordshire,  
OX11 0RA

Fax 01235 433066

Helpline Tel 0800 585794

Helpline E-mail [etbppenq@aeat.co.uk](mailto:etbppenq@aeat.co.uk)

**Energy Consumption Guides:** compare energy use in specific processes, operations, plant and building types.

**Good Practice:** promotes proven energy efficient techniques through Guides and Case Studies.

**New Practice:** monitors first commercial applications of new energy efficiency measures.

**Future Practice:** reports on joint R & D ventures into new energy efficiency measures.

**General Information:** describes concepts and approaches yet to be fully established as good practice.

**Fuel Efficiency Booklets:** give detailed information on specific technologies and techniques.

**Energy Efficiency in Buildings:** helps new energy managers understand the use and costs of heating, lighting etc.

© CROWN COPYRIGHT REVISED 1993 REPRINTED 1996